Prepared for:

ARMSTRONG WORLD INDUSTRIES SUPERFUND SITE
Operable Unit 2
Macon, GA
Docket Number: CERCLA-04-2018-3759

REMEDIAL INVESTIGATION / FEASIBILITY STUDY WORK PLAN ADDENDUM #1 (Revision 1) OPERABLE UNIT 2

Prepared by:

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August 2020

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August 2020

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Acronyms and Abbreviations

Addendum	RI/FS Work Plan Addendum
AIP	Allied Industrial Park
ASTM	American Society for Testing and Materials
AWI	Armstrong World Industries
BEHP	Bis(2-ethylhexyl)phthalate
cDCE	Cis-1,2-dichloroethylene
COPCs	Constituents of Potential Concern
EPA	United States Environmental Protection Agency
DU	Decision Unit
FSP	Field Sampling Plan
FMNOL	Former Macon Naval Ordnance Plant landfill
ft-amsl	feet above mean sea level
ft-bgs	feet below ground surface
HMWPAH	High molecular weight PAHs
ID	Inner diameter
ISM	Incremental Sampling Methodology
LAPA	Local Area Population Assessment
MNOP	Macon Naval Ordnance Plant
MWA	Macon Water Authority
OU1	Operable Unit 1
OU2	Operable Unit 2
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
QAPP	Quality Assurance Project Plan
RAAs	Remedial Action Alternatives
RAOs	Remedial Action Objectives
RI/FS	Remedial Investigation and Feasibility Study
SAIC	Science Applications International Corporation
SOP	Standard Operating Procedure
SPT	Standard Penetration Test
SU	Sampling Unit
TCE	Trichloroethylene
TWG	Technical Work Group
VOCs	Volatile Organic Compounds
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

1.1 Background

The United States Environmental Protection Agency (EPA) issued an Administrative Settlement Agreement and Order on Consent (Docket No. CERCLA-04-2018-3759), requiring a Remedial Investigation and Feasibility Study (RI/FS) for Operable Unit 2 (OU2) of the Armstrong World Industries (AWI) Superfund Site in Macon, Georgia (the "Site"). The August 2019 RI/FS Work Plan (EPS, 2019a) and supporting Field Sampling Plan (FSP) (EPS, 2019b) and Quality Assurance Project Plan (QAPP) (EPS, 2019c) presented the rationale and technical approach for investigating the nature and extent of contamination at the Site, including (but not limited to) sampling of the various environmental media (soil, groundwater, sediment, surface water, and fish tissue) for constituents of potential concern (COPCs). This RI/FS Work Plan Addendum (Addendum) proposes additional investigation of soil and groundwater to supplement the characterization completed during the initial work phase.

1.2 Site Description

The Site is largely a bottomlands floodplain down-gradient of an industrial area located on the southern side of Macon, Georgia in Macon-Bibb County. The Site includes the AWI Remote Landfill, the former Macon Naval Ordnance Plant landfill (FMNOL), the drainage ditches to and from these landfills, and affected sediments and biota in and around Rocky Creek. There are no exact boundaries for the Site; accordingly, the figures show an approximate outline of OU2. There are two other related sites neighboring the Site (OU2): Operable Unit 1 (OU1), which is the AWI Wastewater Treatment Plant (WWTP) Landfill (located northwest of the Site), and the former Macon Naval Ordnance Plant (MNOP), which is now called the Allied Industrial Park (AIP) (located directly north of the Site).

1.3 Document Organization

The remainder of this Addendum is organized as follows:

- Section 2 describes the dynamics (hydrology) of the Rocky Creek floodplain and Site hydrogeologic setting;
- Section 3 summarizes the soil and groundwater sampling completed during the initial work phase of the RI;
- Section 4 presents the proposed work scope for additional soil and groundwater characterization and soil permeability testing;

- Section 5 outlines the protocols and procedures for those work elements not part of the initial work phase (*i.e.*, monitoring well installation and soil permeability sample collection); and
- Section 6 provides the proposed schedule for the work.

2 SITE SETTING

2.1 General Site Setting

The Site (OU2) encompasses approximately 350 acres of forested land on a south-facing slope along Rocky Creek, due south of AIP and southeast of OU1 (Figure 1). Land surface elevation along the slope ranges from 340 feet above mean sea level (ft-amsl) near AIP to 275 ft-amsl along Rocky Creek. The Site is roughly divided in half (north/south) by a historical rail line and a water reclamation facility, which act as a natural boundary between the upland terrace and bottomland subject to flooding from Rocky Creek. During the initial work phase (December 2019 – April 2020), the flood boundary was observed at the toe of the topographic relief provided by the Landfills and generally followed a path parallel to Rocky Creek along the latitude of the southern tip of the Remote Landfill (see Figure 1).

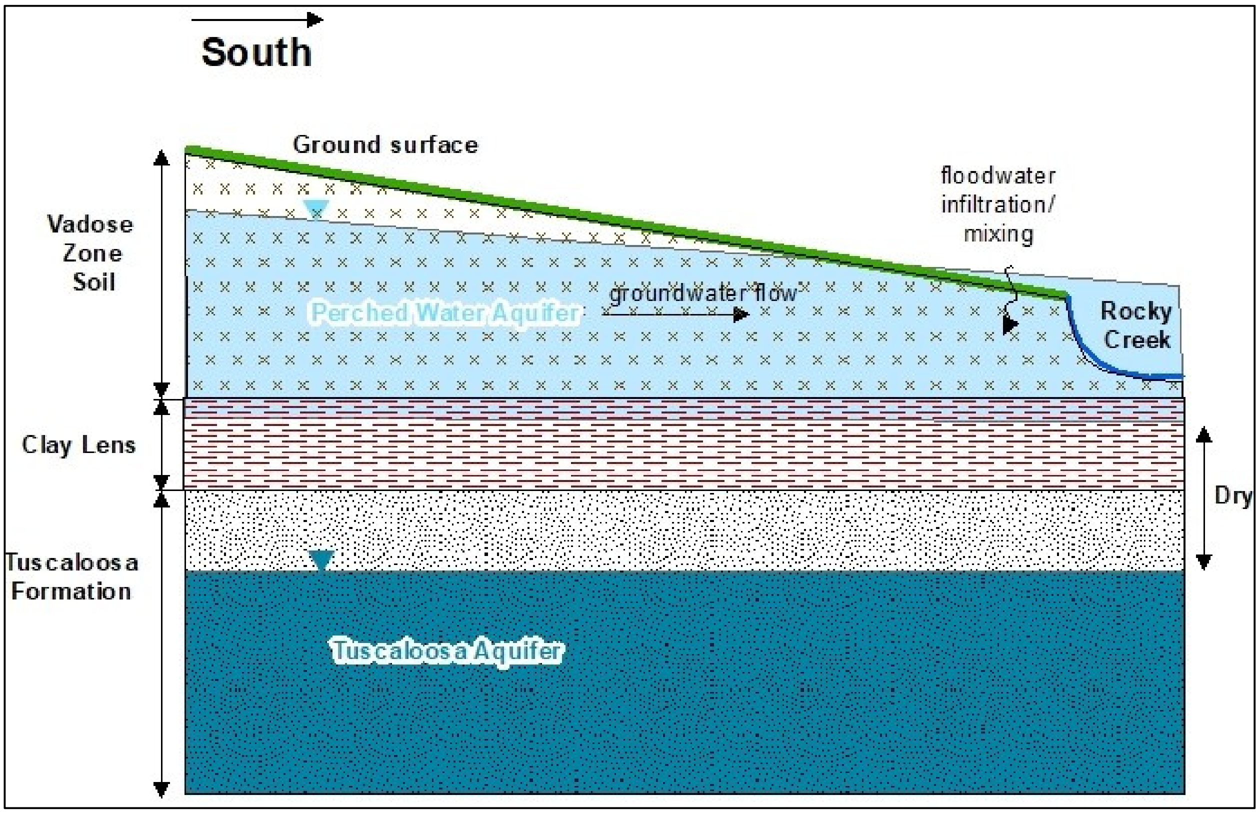
2.2 Floodplain Hydrology

Natural processes of periodic flooding induced by rainfall, accompanied by erosion and deposition, play a crucial role in creating and reshaping the dispersal patterns of nutrients and pollutants (Matys Grygar *et al.*, 2014; Walling *et al.*, 2003) and regulating the geomorphological evolution of the floodplain (Juez *et al.*, 2019). Flood waters and suspended sediments breach the banks of Rocky Creek and spread over the adjacent floodplain along topographically determined floodlines. As the kinetic energy (velocity) of the overbank flow dissipates (aided by the hydraulic roughness imposed by the floodplain vegetation), creek sediment and scoured floodplain soil particles settle out in the water column and are deposited (redistributed) across the floodplain. The length of time that the Rocky Creek floodplain is inundated is contingent upon rainfall intensity and frequency of occurrence, though generally the floodplain remains inundated for several days after a rain event.

Short-term fluctuations in flood stage can significantly influence groundwater and surface water interactions within floodplain environments. The rise of the water channel (*e.g.*, river or creek) induces a kinematic (pressure) wave that displaces floodplain groundwater and causes the bank and near-channel floodplain water table to rise rapidly by the same amount (Cloutier *et al.*, 2014, Jung *et al.*, 2004, Ó Dochartaigh *et al.*, 2012, Wenninger *et al.*, 2004). Upward hydraulic gradients can occur in these zones and, in some instances, cause artesian-like conditions and groundwater discharge (Ó Dochartaigh *et al.*, 2012). The correlation between river stage and groundwater level weakens in the hillslope–floodplain boundary zone where the hydraulic head is driven by inflow of hillslope groundwater, forming a hydraulic gradient toward the base of the hillslope (Bates *et al.*, 2000). The counteracting hydraulic gradients from the hillslope and floodplain form a temporary groundwater ridge, which acts as a barrier to hillslope groundwater reaching the floodplain and limits hillslope contributions to the water channel (Jung *et al.*, 2004). The groundwater ridge dissipates as water recedes (drains) out of the floodplain following a declining river stage and hillslope inflow accumulates above the floodplain water table.

2.3 Hydrogeologic Setting

Previous Site characterization work studies completed by Science Applications International Corporation (SAIC) identified a laterally continuous clay layer beneath OU2 and AIP (SAIC, 2000; SAIC, 2001). The clay layer acts as a low permeability lens or confining layer limiting the interaction between the shallow groundwater and the underlying regional aquifer (the Tuscaloosa Aquifer). The accumulation of rainfall infiltration above the clay lens produces a locally significant "perched" aquifer with a distinct potentiometric surface, as indicated by the stark hydraulic head difference in well pairs staggered vertically across the clay lens (depicted in Figures 2A-C). A simplified schematic of the Site hydrogeologic setting is provided below.



The potentiometric surface of the perched aquifer generally follows the pitch of the confining unit interface, except in the Rocky Creek floodplain where the pitch of the confining unit interface pivots to the east (Figure 3). The groundwater potentiometric surface in this area of the Site is likely to be influenced by the flood stage of Rocky Creek, as described in Section 2.2.[1] The groundwater COPC condition emanating from the area of the Landfills exhibits an easterly

[1] Note, the groundwater potentiometric surface was generated based on water level gauging measurements collected during a low flood stage. Groundwater samples were collected during a higher flood stage.

chemical concentration gradient along the pitch of the confining unit interface despite the apparent directional bias of the flow.

The confining properties of the upper clay layer are demonstrated by the large vertical separation of the hydraulic head between the perched aquifer and the underlying Tuscaloosa Aquifer and the contrasting chemical condition between the two aquifers. Elevated concentrations of COPCs at OU2 and AIP are limited to the perched aquifer, indicating that nominal levels of groundwater contamination have permeated the confining layer. Geotechnical testing is proposed in this Addendum (Section 4.5) to better define the physical property of the shallow confining layer.

3 SUMMARY OF PHASE I RI/FS FIELD INVESTIGATION

3.1 Phase I Soil Characterization Work Scope

The initial soil investigation focused on the low-lying areas north of Rocky Creek and involved a broad analytical suite with additional area-specific testing, including metals[2], polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyl (PCB) Aroclors and congeners, bis(2-ethylhexyl)phthalate (BEHP) (landfills only), and in the Explosives Demolition Area energetics, perchlorates, hexavalent chromium and dioxins/furans. Soil sampling was performed using incremental sampling methodology (ISM) (ITRC, 2012) to accommodate large-scale spatial heterogeneity (*i.e.*, variation in chemical concentration across an area or volume) anticipated as a result of the dynamics of the floodplain setting. The region for which a decision is made based on the ISM sampling is defined as a Decision Unit (DU). A DU may be comprised of one or more Sampling Units (SUs) for which ISM samples are collected.

The soil ISM sampling design included 21 DUs, each comprising one SU (*i.e.*, the DU and SU were one in the same) and targeted the top 6-inches of the soil column. The DUs (not including the reference/background DU) are shown on Figure 4. DU boundaries were determined based on physical/topographic features and wetlands inventory maps. On average, the size of the DUs was 4-5 acres in accordance with the Local Assessment Population Area (LAPA)[3] of a sessile small mammals (*i.e.*, likely the most sensitive wildlife guild). Three replicate samples comprising 30 aliquots of soil were established from each DU according to the procedure described in Section 2.2 of the RI/FS FSP. The processing (*i.e.*, compositing, drying, sieving, and subsampling) of the material was performed at the laboratory according to its Standard Operating Procedure (SOP).[4]

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[2] Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, silver, thallium, vanadium and zinc.

[3] The ODEQ Technical Workgroup (TWG) Report (ODEQ, 2017) advances the concept of LAPA, derived by combining the overlapping home ranges of a population to appropriately assess the effect of a condition on a population and not the individual, thus representing the minimum land surface area that can sustain a healthy population in absence of any stressors. Home range size and LAPAs for various environmental receptors are provided in Table 1 of Appendix B.3 of the ODEQ TWG Report.

[4] The laboratory's ISM sample processing SOP was included in the Appendix of the RI/FS FSP.

3.2 Phase I Groundwater Sampling Work Scope

A total of 38 monitoring wells were installed in the 1990s (and 1989) to characterize the groundwater condition emanating from the Landfills (ESE, 1990; ERM, 1995; RUST, 1997; SAIC, 2000). The majority of well installations are single well points screened in the perched aquifer, except for two well groupings (MW-2 and MW-2B, and MW-4, MW-11, and MW-4B) which were installed to provide a vertical assessment of groundwater. Nine additional monitoring wells were installed along the historical rail line and on the upland terrace in 2000-2001, to better define the limits of the groundwater condition emanating from the AIP property (SAIC, 2001).

The recent (December 2019) episode of groundwater monitoring focused on a subset[5] of 21 monitoring wells in the region of the Landfills (Figure 5) and involved a comprehensive analytical suite. The specific wells sampled (along with their total depth) and the analytical testing regimen are summarized below.

Well	Depth (ft bgs)	Well	Depth (ft bgs)	Well	Depth (ft bgs)	Well	Depth (ft bgs)
MW-1	32	MW-5	19	MW-13	9.5	MW-20	17
MW-2	24.5	MW-7	11.5	MW-14	11.5	MW-21	11.5
MW-2B	57	MW-8	10	MW-15	19	MW-79	14.5
MW-3	23.5	MW-9	10.5	MW-16	9		
MW-4	19	MW-10	11	MW-17	19		
MW-4B	96	MW-12	19	MW-18L	20		

Groundwater Analytical Testing Regimen [(1)]				
Metal – same list as for soil (EPA Method 6010C)	Mercury (EPA Method 1631E)	PCB Aroclors and congeners (EPA Method 8082A)	Specific VOCs [(2)] (EPA Method 8260C)	BEHP (EPA Method 8270D)
Cyanide (EPA Method 335.4)	Dieldrin (EPA Method 8081B)	Energetics (EPA Method 8330B)	Total Organic Carbon (EPA Method SM5310)	Nitrates (EPA Method 300)
Notes: [(1)] Groundwater samples were unfiltered. [(2)] 1,1-dichloroethene, carbon tetrachloride, cis-1,2-dichloroethene, trichloroethene, vinyl chloride				

[5] Redundancies (*i.e.*, co-located wells with similar construction and/or reporting a similar historical result for trichloroethene) and damaged/destroyed wells within the Remote Landfill were not included in the monitoring regimen.

Monitoring wells were sampled using a peristaltic pump according to the "Low-Flow" purging method described in Section 2.3 of the RI/FS FSP.

3.3 Preliminary Findings for Soil and Groundwater Phase I Assessment

Data collected from execution of RI/FS Work Plan have been electronically transmitted to EPA in monthly progress reports (EPS, 2020a; EPS, 2020b) and personal communication (Bullman, 2020). The data indicate an elevated soil condition with no discernable distribution pattern across the bottomland of OU2, and confirm the presence of a contaminant plume in the perched aquifer emanating from the area of the Landfills. The primary soil and groundwater COPCs and receptors potentially driving risk and/or remediation at the Site were identified based on risk screening exercise using the new data (Bullman, 2020); the results of that risk screening exercise are summarized in the table below. Note, that the screening did not identify any human receptors for soil.

	Soil **Ecological Receptor**	**Groundwater** **Human Receptor**
PCBs	X	
HMWPAHs (1)	X	
Cadmium	X	
TCE (2)		X
Vinyl Chloride		X

(1) High molecular weight PAHs

(2) Trichloroethene

Based on a discussion with EPA on July 8, 2020, EPA has agreed that the Respondents should perform additional soil and groundwater characterization downgradient of the elevated condition with focus on key risk-driving COPCs.

4 PROPOSED PHASE II WORK SCOPE

4.1 Overview

The proposed work scope for additional soil characterization[6], as well as monitoring well installation and sampling and permeability testing of the clay confining layer is described herein. Soil and groundwater sample collection for chemical testing will follow the methodology and procedures described in the RI/FS Work Plan and FSP (*e.g.*, ISM for soil sampling, "Low-Flow" groundwater sampling methodology). The analytical testing methods pertinent to the sampling and the collection and analysis of quality assurance/quality control (QA/QC) samples are provided in the RI/FS QAPP. Protocols and procedures for newly proposed work elements (*i.e.*, monitoring well installation and soil permeability sample collection) are discussed in Section 5 of this Addendum. Field SOPs and laboratory analytical methods pertinent to these work elements are presented in the Appendix.

4.2 Phase II Floodplain Soil Characterization

Three ISM DUs (DUs 19, 20, and 21) are proposed along Rocky Creek as depicted on Figure 6, for the purpose of bounding the elevated floodplain soil condition characterized during Phase I bordering the northern area along Rocky Creek. The new ISM DU boundaries follow natural geomorphic features in the area and although are of larger dimensions compared to the Phase I units, the proposed scale (size) of the DUs is considered acceptable because previous soil characterization revealed a relatively homogenized condition along Rocky Creek, as anticipated due to the dynamics (hydrology) of the floodplain. Therefore, it is reasonable to assume a finer spatial resolution of contaminant variability is not needed for floodplain soils.

The analytical testing regimen for floodplain soil will address the risk drivers and comprise PCBs (Aroclors and congeners by EPA Method 8082A), high molecular weight PAHs (HMWPAHs) (EPA Method 8270DSIM), and cadmium (EPA Method 6010C).

4.3 Phase II Upland Soil Characterization

One additional upland soil ISM DU (DU-22) is proposed upgradient of the elevated PCB condition in the northwest corner of OU2 (also shown on Figure 6), to investigate potential transport mechanisms responsible for the occurrence of PCBs upgradient of the Landfills. Accordingly, ISM samples collected from this DU will be tested for PCBs (Aroclors and congeners) only (EPA Method 8082A).

[6] The soil characterization focuses on the top 6 inches of the soil column consistent with the Phase I soil sampling.

4.4 Groundwater Investigation

The proposed groundwater investigation involves installing and sampling three monitoring wells in the perched aquifer (MW-100, MW-101, and MW-102), to investigate the easterly concentration gradient of chlorinated ethenes emanating from the area of the Landfills. The locations of proposed monitoring wells are depicted on Figure 7. Well screens will be set at a depth from approximately10-20 feet below ground surface (ft-bgs) terminating at the interface between the perched aquifer and shallow clay layer. Details regarding methods for well boring construction and monitoring well completion are provided in Section 5.1 and 5.2, respectively, of this Addendum. Groundwater samples will be analyzed for the same list of volatile organic compounds (VOCs) as for the Phase I groundwater sampling (EPA Method 8260C).[7]

4.5 Permeability Testing of the Clay Confining Layer

Permeability testing is proposed to provide a quantitative measure of the confining layer properties. Testing will be accomplished by obtaining an undisturbed core of the confining layer material from each of the new monitoring well installations discussed in Section 4.4 (the sample collection methodology is described in Section 5.1 of this Addendum). The permeability characteristics of the confining layer material will be determined using American Society for Testing and Materials (ASTM) Method D5084, or equivalent method.

[7] 1,1-dichloroethene, carbon tetrachloride, cis-1,2-dichloroethene (cDCE), trichloroethene (TCE), vinyl chloride

5 FIELD SAMPLING PLAN

5.1 Monitoring Well Borings and Sampling for Permeability Testing

Well borings for new monitoring well installations (MW-100, MW-101, and MW-102) will be completed using a Geoprobe® (or equivalent) hollow stem auger track rig and 4.25-inch inner diameter (ID) diameter auger bit. A continuous split spoon sampler will be driven inside the hollow stem auger to collect samples for lithological descriptions, and to conduct a standard penetration test (SPT) for evaluating the geotechnical engineering properties (*e.g.*, relative density) of subsurface soils. Borings will be advanced from ground surface to the top of the confining layer, at which point a Shelby Tube sampler (of dimensions 3-inches diameter and 30-inches in length) will be advanced to extract an undisturbed sample of the confining layer material. The Shelby Tube will be capped, sealed, and submitted to the laboratory for permeability testing according to Section 7.2 of *Soil Sampling (SESDPROC-300-R3)* developed by the EPA (EPA, 2014).[8] After the Shelby Tube is removed from the borehole, the lower portion of the borehole will be backfilled with bentonite pellets to the perched aquifer/clay interface.

5.2 Monitoring Well Construction

Monitoring wells will be installed in accordance with Sections 2.3 (Filter Pack Seal – Bentonite Pellet Seal (Plug)) and 2.4.1 (Well Installation [single-cased well]) of EPA Region 4 Guidance: *Design and Installation of Monitoring Wells (SESDGUID-101-R1)* (EPA, 2013). Each monitoring well will consist of 2-in. Schedule 40 PVC casing. Each well will be screened in the lower 10-feet atop the aquifer/clay interface with 0.010-inch slotted screen with a sand filter pack placed in the annular space to 2 feet above the screened interval. The remaining annular space will be sealed with a bentonite pellet plug of 2 feet followed by grout to the ground surface. The bentonite plug will be allowed approximately 8 hours to hydrate prior to grouting.

All monitoring wells will be completed as stick-ups and set in a stand-up steel protective casing at the center of a 3-foot by 3-foot by 4-inch thick concrete well pad constructed at the ground surface. The top-of-casing (TOC) will be marked for surveying purposes, a well cap will be placed on the well, and a lock will be placed on the stand-up steel casing.

[8] This SOP was provided in the RI/FS FSP.

5.3 Well Development

Once the grout seal is allowed to cure for 24 hours, the wells will be developed using a downhole pump according to Section 2.7 of *Design and Installation of Monitoring Wells (SESDGUID-101-R1)* (EPA, 2013). The pump intake will be raised and lowered through the screened section of the well. The well will be developed until the water is free of visible sediment and pH and specific conductivity have stabilized.

5.4 Monitoring Well Surveying

Locations (coordinates) of all monitoring wells will be determined by a State-licensed surveyor. The surveyor will also survey top of well casing and ground surface elevations with an auto level instrument, consistent with Section 4 of *Groundwater Level and Well Depth Measurement* (LSASDPROC-105-R4) developed by the EPA (EPA, 2020).

6 SCHEDULE

The field investigation will commence as soon as practicable after EPA's approval of the Addendum. The soil sampling along Rocky Creek will need to be conducted under a low flood stage. Accordingly, the timing of the soil sampling will be contingent upon the weather. Data obtained from execution of this Addendum will be incorporated with initial RI/FS characterization data into the comprehensive Site Characterization Summary Report, which will provide the basis for developing the Baseline Risk Assessment and Remedial Action Objectives (RAOs).

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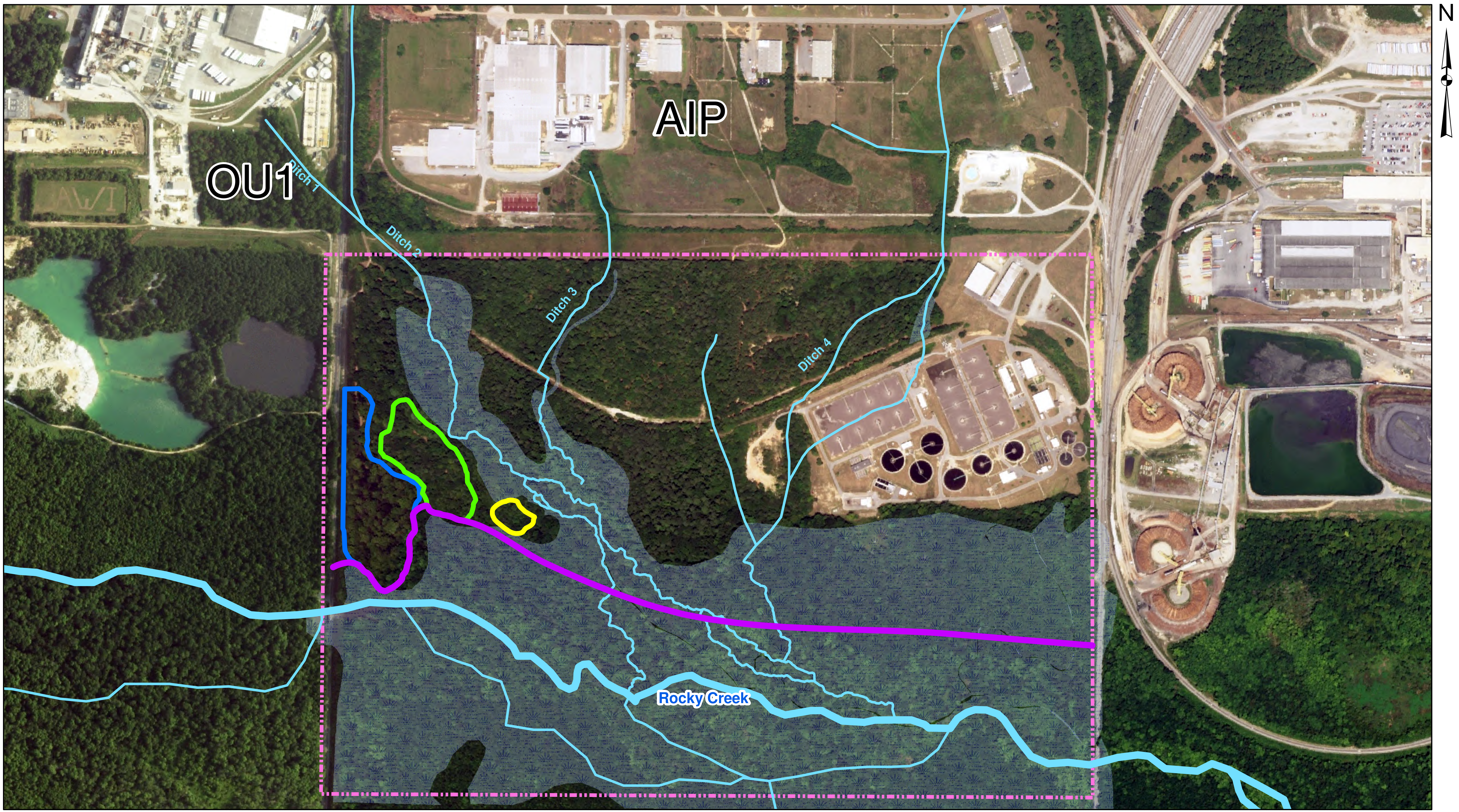
FIGURES



0 250 500 1,000

Feet

Legend

FMNOL

Remote Landfill

Explosives Demo Area

2019/2020 Observed Flooding Boundary (approx)

OU2 (approx)

Wetlands

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Site Setting

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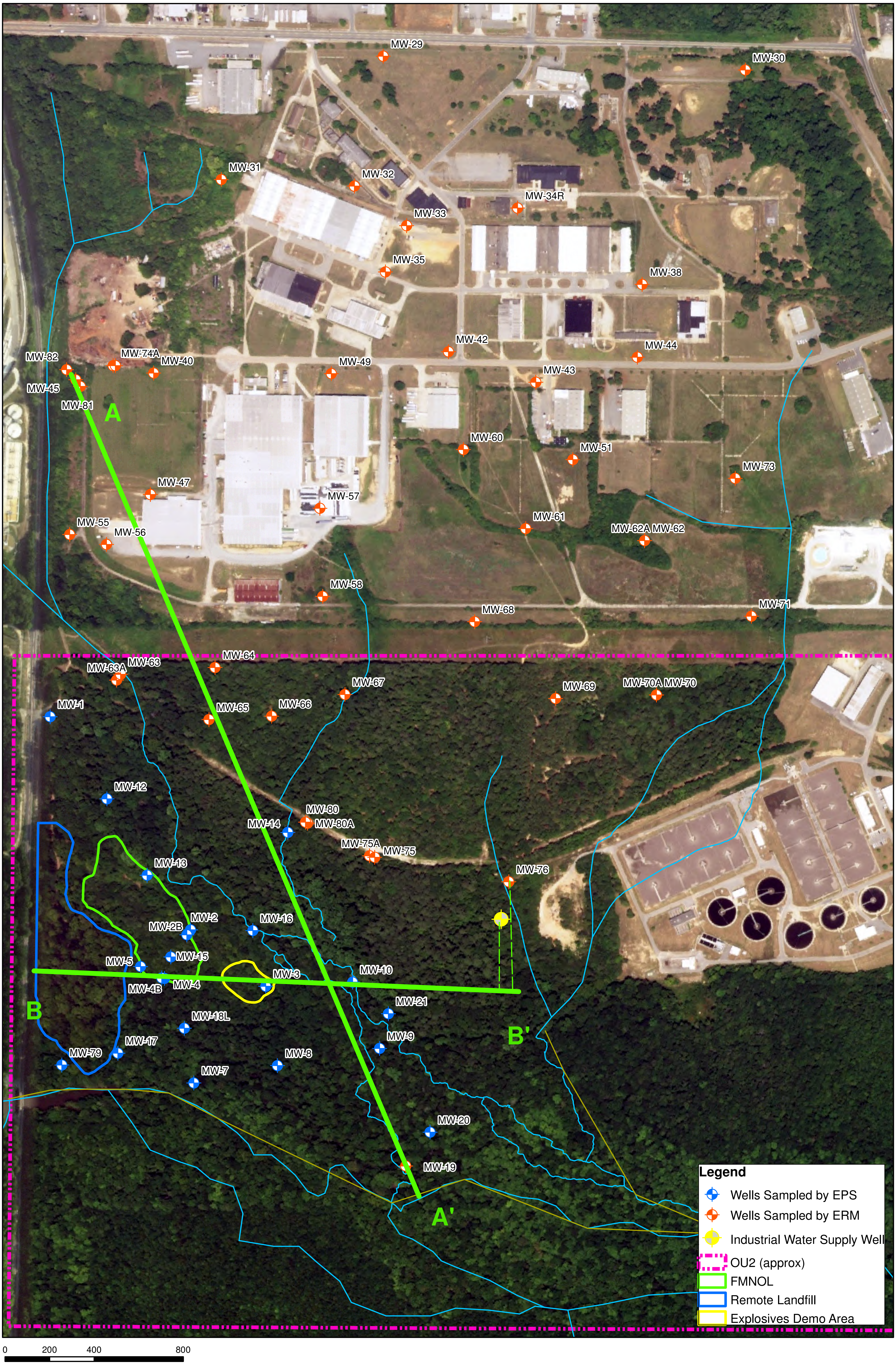
Figure No. 1



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Plan View of Cross Sections

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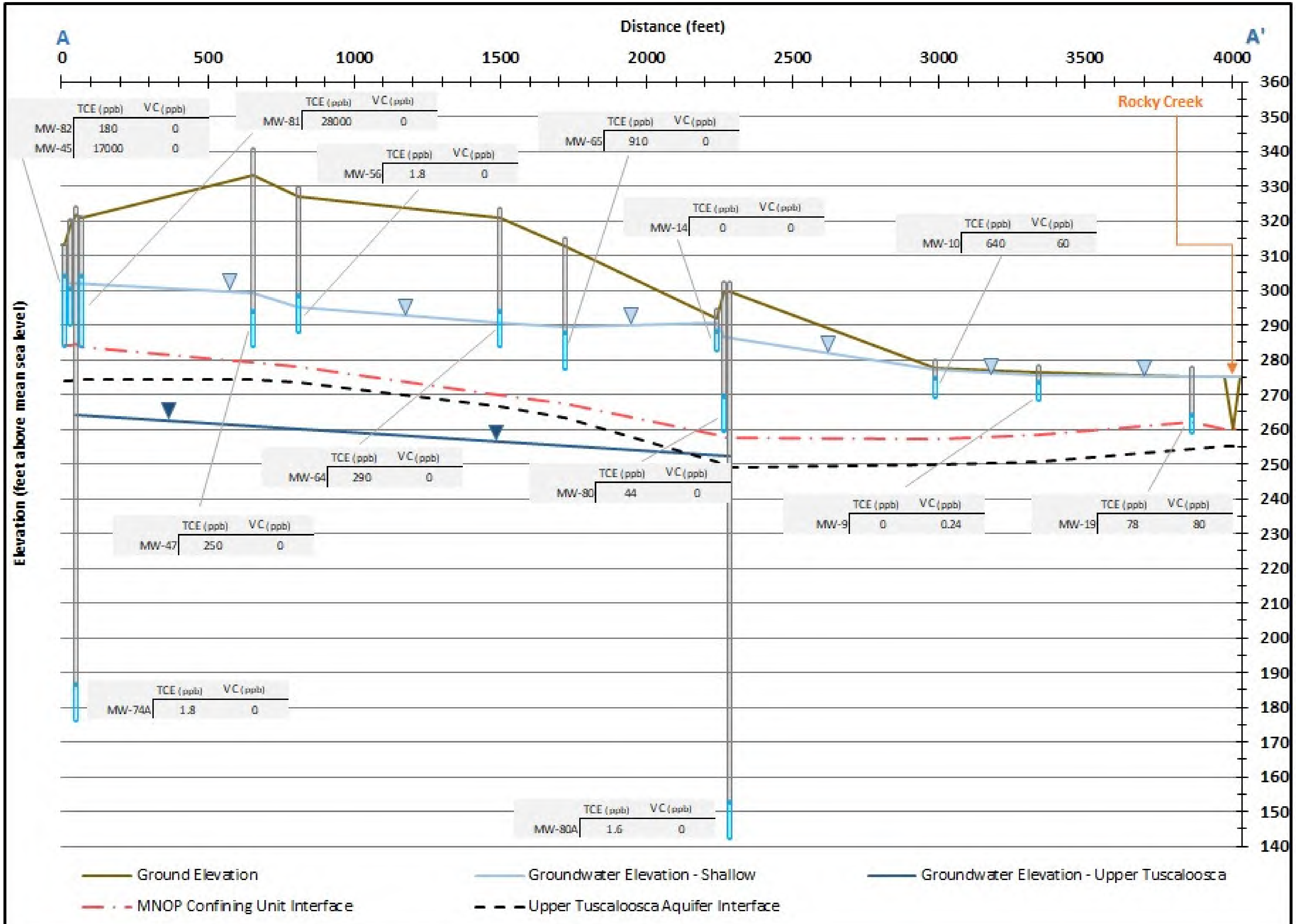
Figure No. 2A



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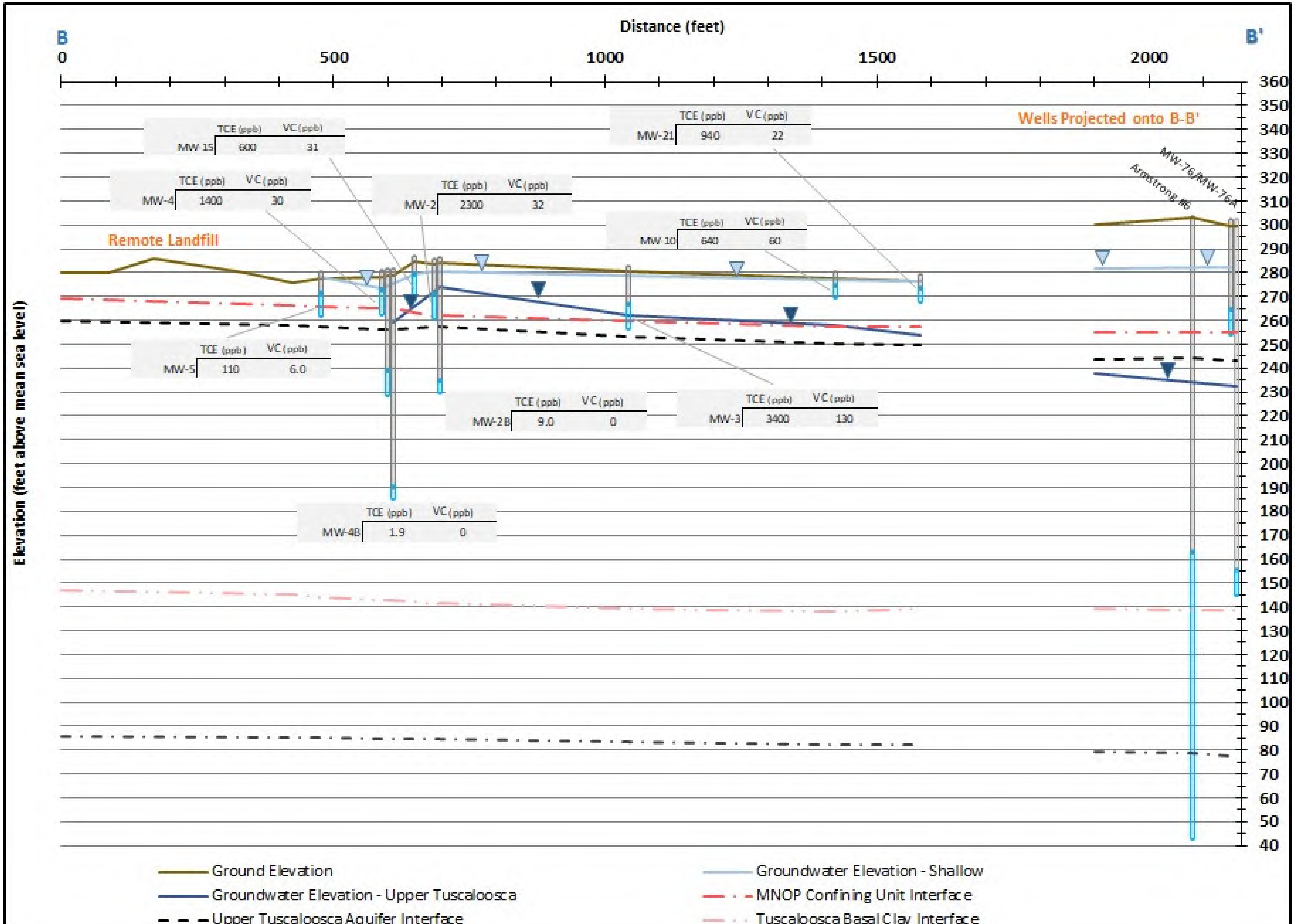
Geological Cross Section from AIP to Rocky Creek

Figure No. 2B



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Geological Cross Section from West to East Across OU2

Figure No. 2C

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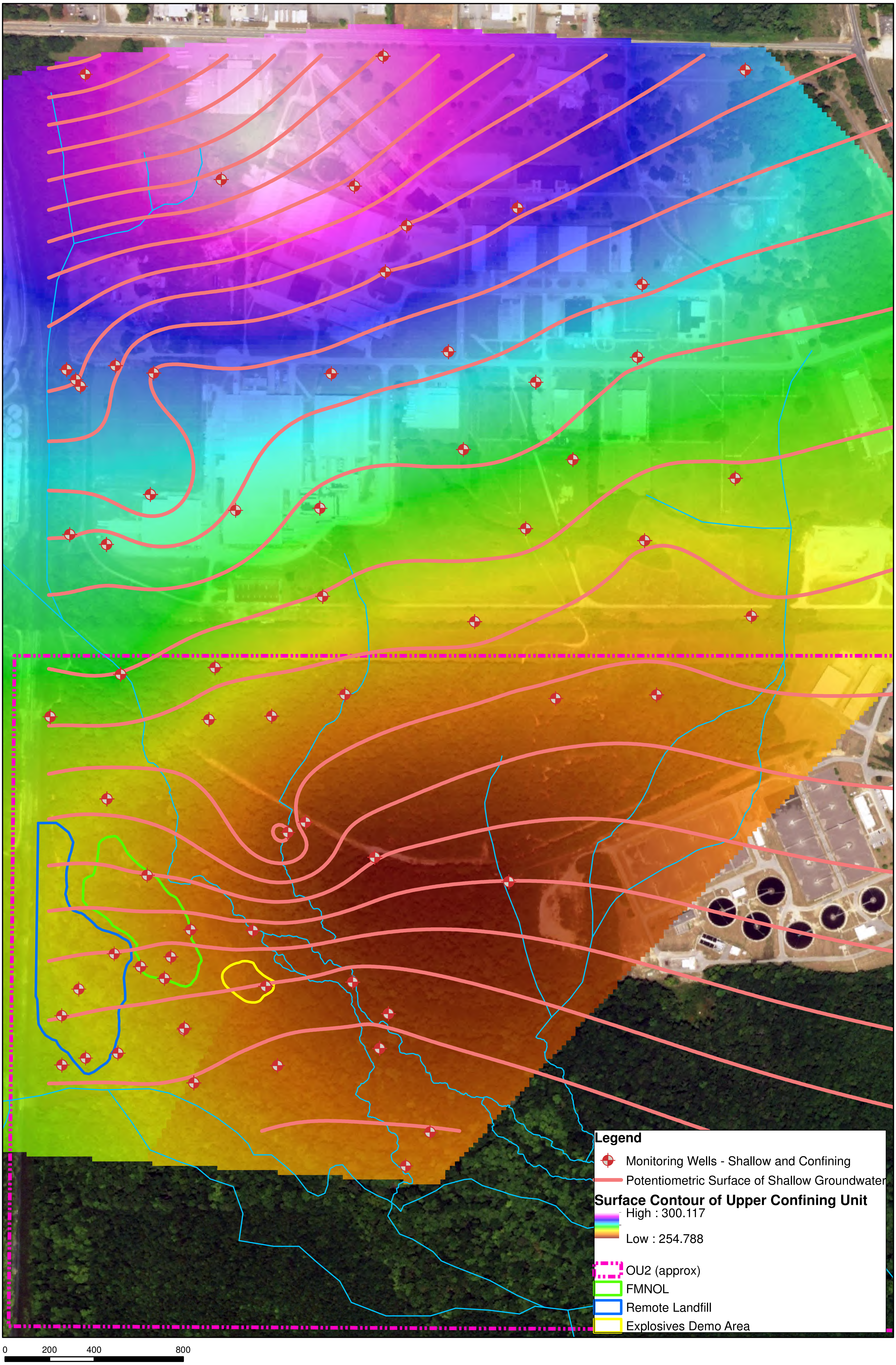

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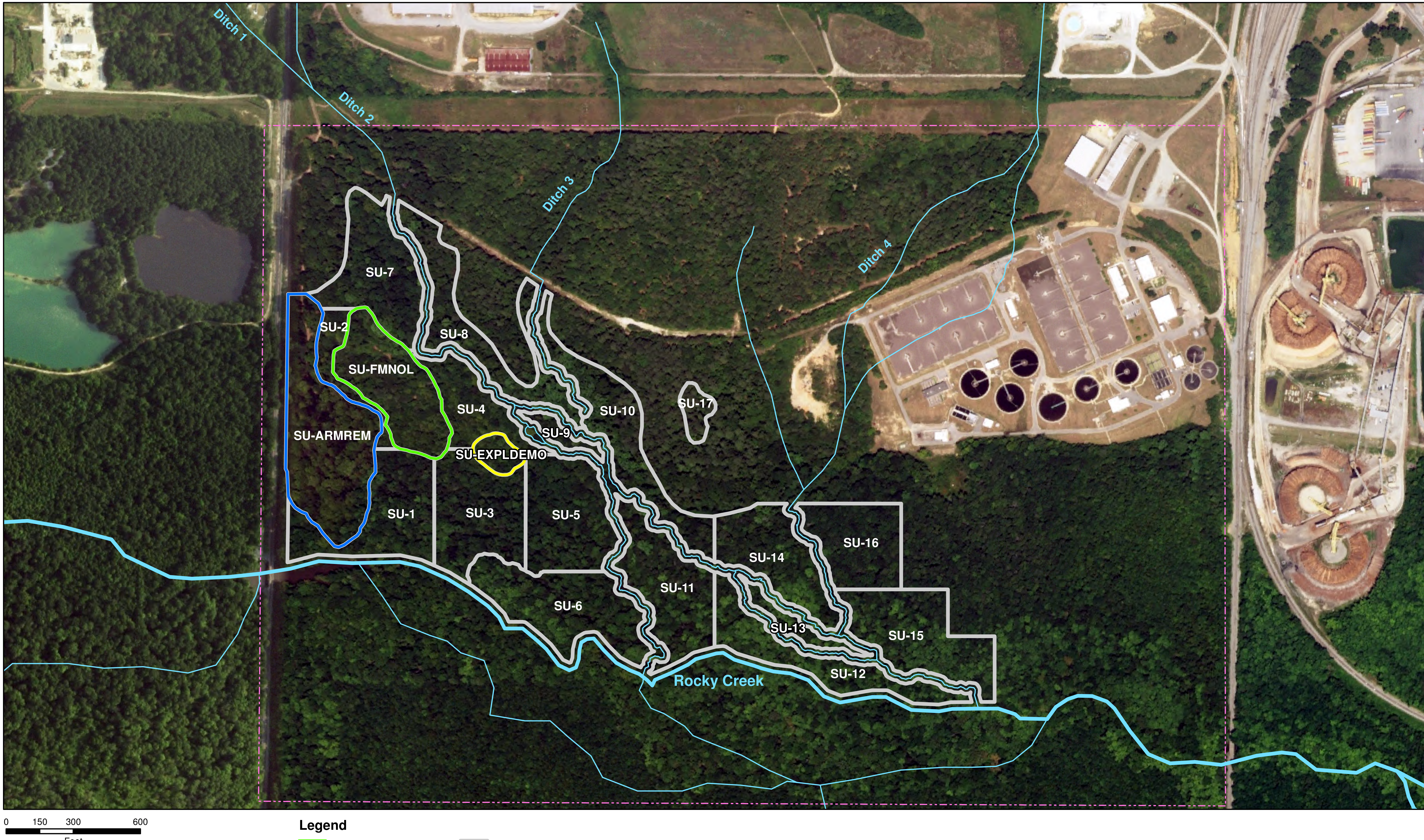
Contour of the Clay Confining Unit Interface

Figure No. 3



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Initial RI Soil Characterization ISM DUs

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Figure No. 4

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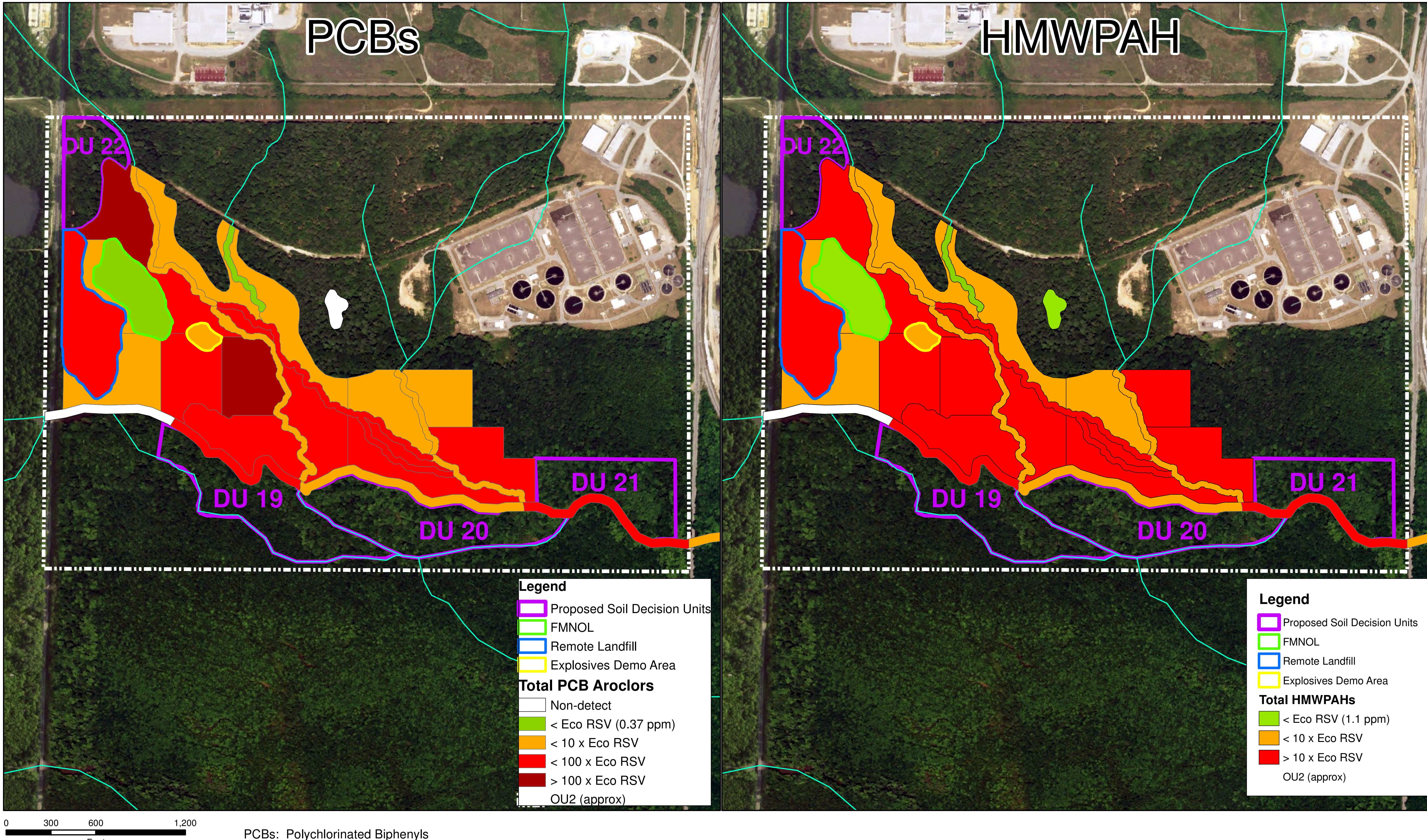
December 2019 Groundwater Monitoring

Figure No. 5



PCBs: Polychlorinated Biphenyls
HMWPAHs: High Molecular Weight Polycyclic Aromatic Hydrocarbons
Eco RSV: Revised Ecological Screening Value
ppm: parts per million

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Proposed Soil ISM DUs

Figure No. 6

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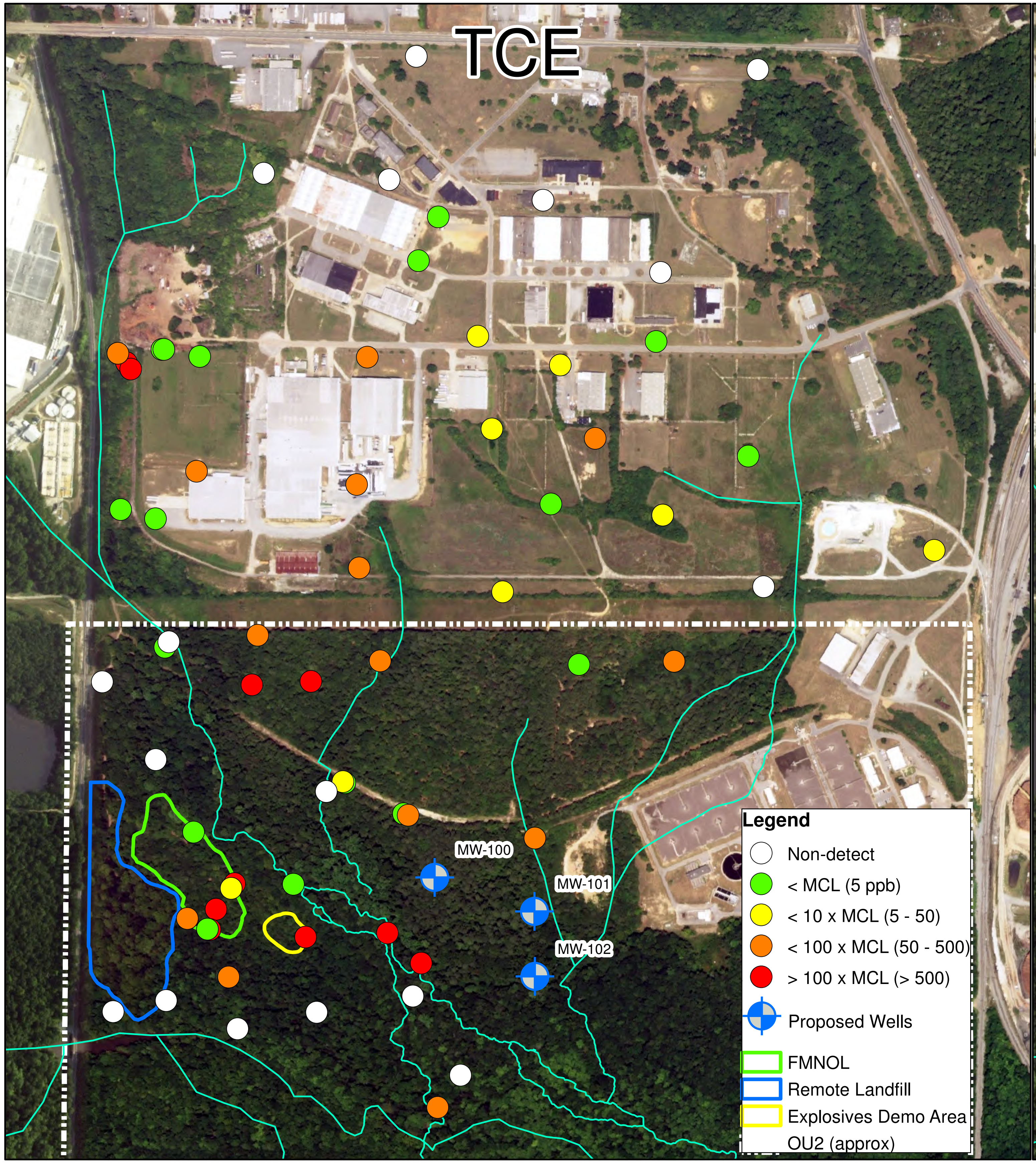

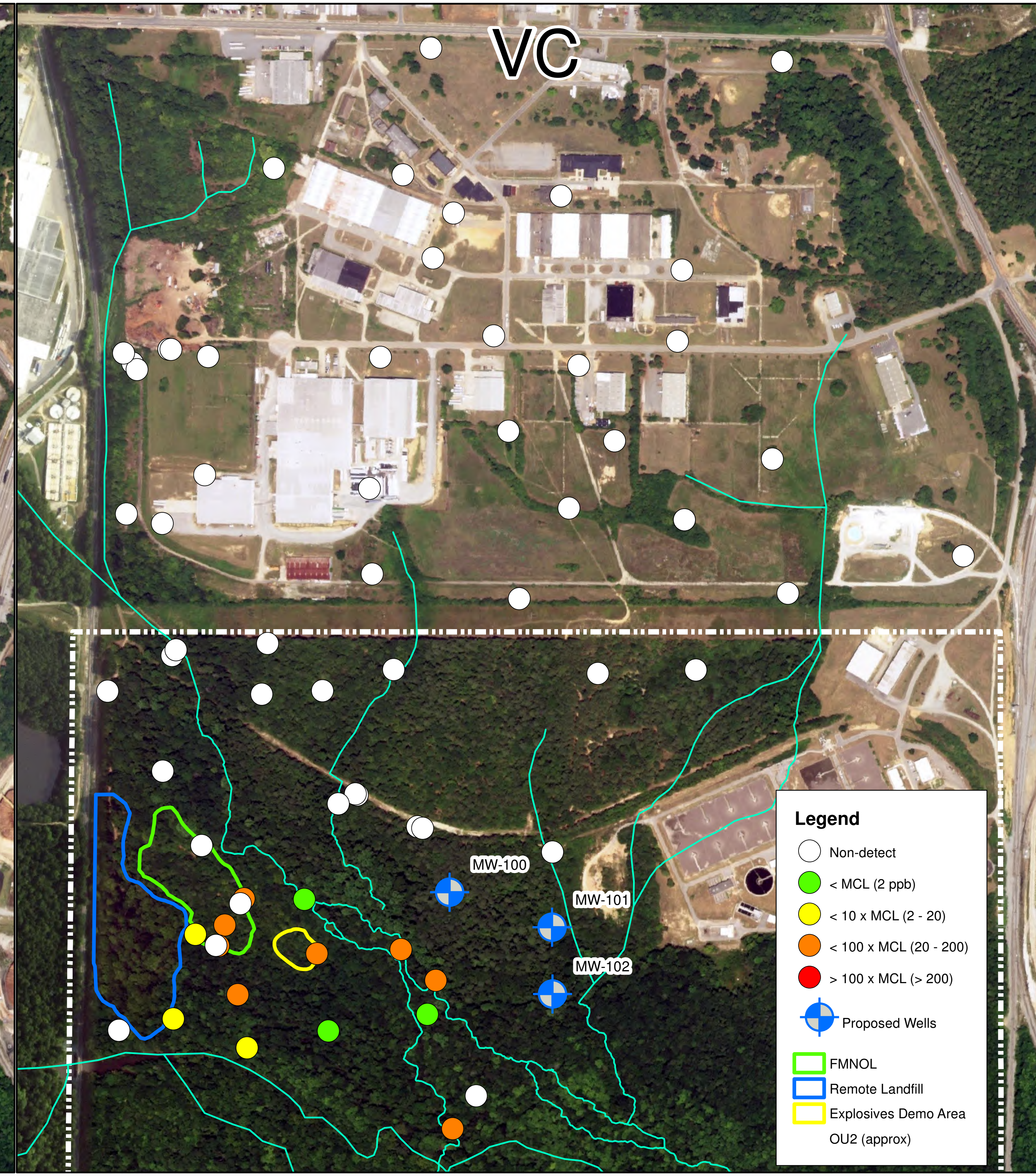

0 300 600 1,200
Feet

TCE: trichloroethene
VC: vinyl chloride
MCL: maximum contaminant level
ppb: parts per billion

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Locations of Proposed Monitoring Well Installations

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Figure No. 7

APPENDIX A
Field and Laboratory SOPs

Technical Information

Reference Number: ASTM D5084-16

Test Method Title: Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter

Test Property: Hydraulic conductivity

Test Specimen Size: Length to diameter ratio of at least 1:1; typically 2.87 or 4.00 inch diameter (from Shelby tube or remolded sample)

Number of Test Specimens: 1

Test Equipment: Permeameter
Pressure panels (hydraulic control system)
Vacuum pump
Thermometer
De-aired water system
Trautwein permometer for Method F constant volume test.

Standard Operating Procedure

1. If sample is undisturbed:
   Extrude from tube, cut ends plane and perpendicular, and trim. If voids are present by removing pebbles or removing crumbling areas they may be filled with remolded material from trimmings of the specimen. Prepare such that there is no moisture loss.

2. If sample is remolded:
   Compact specimen to specified density and moisture content using metal mold, scarifying each lift prior to placing the next.

3. Upon completion of sample preparation, measure and record the sample height and diameter in three locations and average. Measure and record the sample mass. Determine the moisture content of the material by using trimmings or unused portion of sample.

4. Place specimen on soaked filter paper disk which sits on a saturated porous stone and placed on base of bottom section of permeameter. Place another soaked filter paper, porous stone and top cap on top of specimen. Using flexible membranes and O-rings, seal specimen, top cap and base plate.

5. Attach cell and fill area surrounding the specimen with water. Begin de-airing specimen with small vacuum. Hook permeameter up to Pressure Panel. Flush out the system by opening flow line valves.

6. Fill pressure panels with de-aired water – tap or bottled, not distilled.

7. Apply cell pressure to 10 psi and backpressure (specimen pressure) to 5 psi (both top and bottom of specimen). Increase pressures by 5 psi measuring and recording changes in volumes. Measure b-value

after each increment. Once a 0.95 b-value is achieved stop increasing pressures. This may take several days. [note: if client requests an effective stress other than 5 psi, the pressure difference between the cell and sample pressure will be changed to accommodate that request]

METHOD A (Constant Head Test)

8. After backpressure saturation, induce flow by increasing bottom sample pressure (inflow). Typically a 2 psi difference is sufficient between bottom and top portions of sample keeping a 5 psi difference (effective stress) between the sample and cell. This difference (which directly affects the gradient) should be checked against recommended gradients in the test standard section 8.5.1.

9. Begin recording inflow and outflow vs time. Calculated permeability for each set of readings.

10. Test is complete when: at least 4 values of permeability have been determined, the ratio of rate of inflow to rate of outflow shall be between 0.75 and 1.25 for the last four consecutive permeability determinations, and the hydraulic conductivity is steady. Steady is defined as when four or more readings fall within 25% of the mean value for permeabilities greater than 1×10^{-8} cm/sec or within 50% for permeabilities less than 1×10^{-8} cm/sec.

11. Record temperature and correct permeability value to 20 ºC.

12. After completion of permeation, reduce the confining, influent and effluent pressures taking care not to change the volume of the specimen. Disassemble the permeameter cell and remove the test specimen. Measure and record the final height and diameter in three locations and average. Measure the mass of the specimen. Determine the final moisture content by using the entire specimen or using a cross section of the specimen.

13. Calculate permeability as follows:

    $k = QL/Ath * R_t$

    where:

    k = permeability, m/sec
    Q = quantity of flow, taken as the average of inflow and outflow, m^3
    L = length of specimen along path of flow, m
    A = cross-sectional area of specimen, m^2
    t = interval of time, s, over which flow, Q, occurs
    h = difference in hydraulic head across the specimen, m of water
    R_t =temperature correction (IF NEEDED)

METHOD B (Falling Head-Test) – GTX Georgia

14. Create a head using a burette

15. Open valve and record height of water in burette (initial) and start timer

16. Stop flow and stop timer record the height in the burette (final).

17. Continue permeation until a least four values of hydraulic conductivity are obtained over an interval of

time in which the hydraulic conductivity is steady.

METHOD C (Increasing Tailwater Level) – GTX Georgia

18. If the water pressure at the downstream end of the test specimen rises during an interval of time, periodically measure and record either the quantity of inflow and outflow or the change in water level in the influent and effluent burettes.

19. Continue permeation until a least four values of hydraulic conductivity are obtained over an interval of time in which the hydraulic conductivity

METHOD F (Constant Volume) - refer to Figure 2

De-air permometer:

20. Connect line #5 to port #4 and line #6 to port #3. Slowly open port #4 then open port #3.

21. Close port #3. Slowly open valve #8 drawing air bubbles from the line into top reservoir of permometer. Close valve #8 once all air is out of line.

22. Open port #3, close port #4. Slowly open valve #7 to draw air out of top reservoir. The Mercury column will rise during this step. Close valve #7 when the Mercury level reaches 20. Re-open port #4. If necessary, repeat step 4 until all air is visibly removed from top reservoir.

23. Open valve #8 slowly. Leave open for approximately 5 seconds to remove any residual air within line. Close valve #8 and repeat for valve #7 carefully watching Mercury level.

Flow phase:

24. Close port #1. Slowly open valve #7 drawing Mercury to required gradient level (Z_1). See test standard section 8.5.1 for appropriate gradients. Close valve #7 and immediately close port #2.

25. When the top of the Mercury meniscus falls to the next graduation on the column, start timing and record level of Mercury as Z_1. Record for a minimum of 0.2 graduations on the column or at least 30 seconds, whichever takes longer. Record time and Mercury level (Z_2). Record temperature.

26. Calculate gradient as follows:

    $i = [(Z_1 \times 12.6) / L]$

    where:
    i = gradient
    L = length of sample, cm

27. Calculate permeability value as follows:

    $k = (-2.395 \times 10^{-3}) \times (L/At) \times (\ln[1-(\Delta Z/Z_1) \times 1.040953] \times R_t$

    where:
    - k = permeability, cm/sec
    - L = length of sample, cm
    - A = area of sample, cm^2
    - t = time, sec
    - R_t =temperature correction (IF NEEDED)

28. Repeat until 4 values of permeability are obtained over a period of time where readings fall within 25% of the mean value for permeabilities greater than 1×10^{-8} cm/sec or within 50% for permeabilities less than 1×10^{-8} cm/sec.

29. After completion of flow phase close all valves, reduce pressures taking care not to change the volume of the specimen. Disassemble the permeameter cell and remove the test specimen. Measure and record the final height and diameter in three locations and average. Measure the mass of the specimen. Determine the final moisture content by using the entire specimen or using a cross section of the specimen.

30. Report: sample identification, descriptive information, specimen type, initial and final dimensions, moisture content, and density of specimen, permeant used, magnitude of cell and sample pressures, effective consolidation stress, gradient used, average hydraulic conductivity over the last four readings.

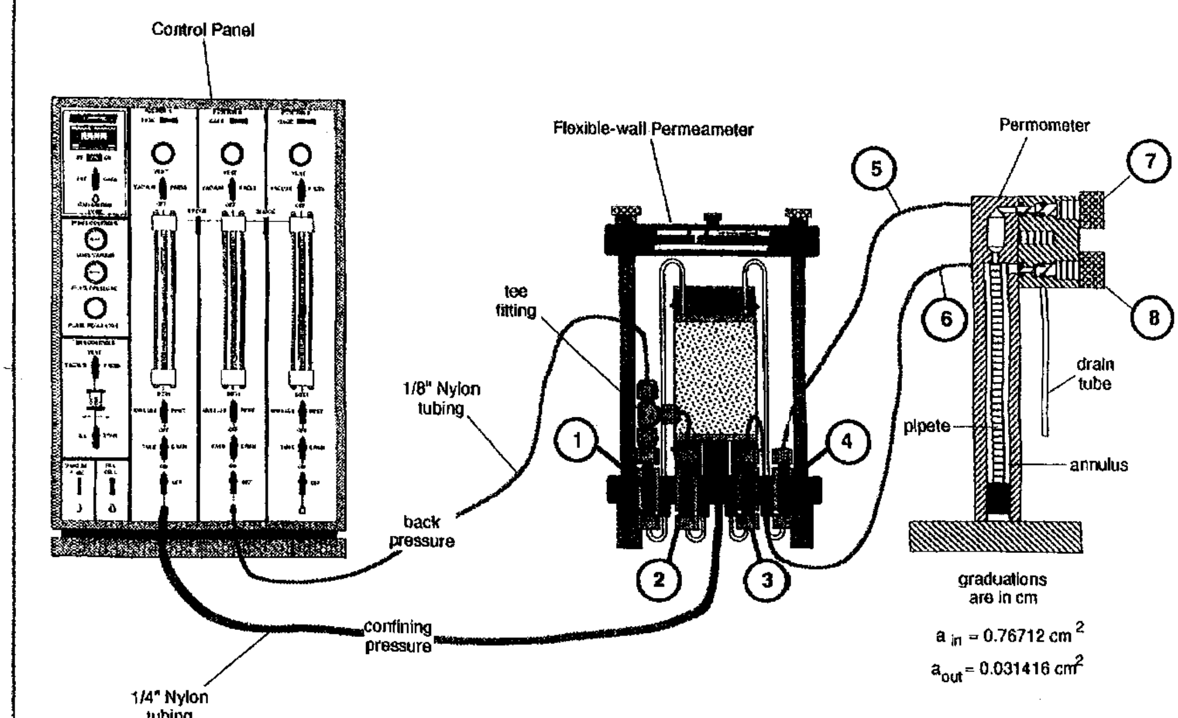

Fig. 2 Permometer Connection to Flexible-Wall Perneameter

Region 4 **U.S. Environmental Protection Agency** **Science and Ecosystem Support Division** **Athens, Georgia**
GUIDANCE
Title: **Design and Installation of Monitoring Wells**

Effective Date: January 29, 2013	**Number:** SESDGUID-101-R1

Authors
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Revision History

This table shows changes to this controlled document over time. The most recent version is presented in the top row of the table. Previous versions of the document are maintained by the SESD Document Control Coordinator.

History	Effective Date
SESDGUID-101-R1, *Design and Installation of Monitoring Wells*, replaces SESDPROC-101-R0. **General:** Corrected any typographical, grammatical and/or editorial errors. **Cover Page:** The Enforcement and Investigations Branch Chief was changed from Antonio Quinones to Danny France. The FQM was changed from Laura Ackerman to Bobby Lewis. **Section 1.2:** Added the following statement: Mention of trade names or commercial products does not constitute endorsement or recommendation for use. **Section 1.3:** Omitted the reference to the H: drive of the LAN. **Section 1.4:** Replaced the “SESD Operating Procedure for Field Records and Documentation, SESDPROC-204-Most Recent Version” with its updated version, the “SESD Operating Procedure for Logbooks, SESDPROC-010, Most Recent Version. **Section 1.5.1:** Updated the SHEMP Manual reference to reflect that the most recent version of the Manual will be used. **Section 1.5.2:** On the second bullet, replaced the reference with the “SESD Operating Procedure for Logbooks (SESDPROC-010).”	January 29, 2013
SESDGUID-101-R0, *Design and Installation of Monitoring Wells*, Original Issue	February 18, 2008

TABLE OF CONTENTS

1 General Information

1.1 Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when designing and installing permanent and temporary groundwater monitoring wells to be used for collection of groundwater samples.

1.2 Scope/Application

The procedures contained in this document are to be used by field personnel when designing, constructing and installing groundwater monitoring wells. On the occasion that SESD field personnel determine that any of the procedures described in this section are either inappropriate, inadequate or impractical and that another procedure must be used for any aspect of the design, construction and/or installation of a groundwater monitoring well, the variant procedure will be documented in the field log book, along with a description of the circumstances requiring its use. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

This procedure was prepared by persons deemed technically competent by SESD management, based on their knowledge, skills and abilities and has been tested in practice and reviewed in print by a subject matter expert. The official copy of this procedure resides on the SESD local area network (LAN). The Document Control Coordinator is responsible for ensuring the most recent version of the procedure is placed on the LAN and for maintaining records of review conducted prior to its issuance.

1.4 References

USEPA Region 4 Environmental Investigations Standard Operating Procedures and Quality Assurance Manual (EISOPQAM), November 2001

USEPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Science and Ecosystem Support Division, Region 4, Athens, GA, Most Recent Version

SESD Operating Procedure for Field Sampling Quality Control, SESDPROC-011, Most Recent Version

SESD Operating Procedure for Field Equipment Cleaning and Decontamination, SESDPROC-205, Most Recent Version

SESD Operating Procedure for Logbooks, SESDPROC-010, Most Recent Version

SESD Operating Procedure for Groundwater Sampling, SESDPROC-301, Most Recent Version

SESD Operating Procedure for Management of Investigation Derived Waste, SESDPROC-202, Most Recent Version

EPA/540/S-95/503, *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation*

ASTM standard D5092, *Design and Installation of Ground Water Monitoring Wells in Aquifers*

1.5 General Precautions

1.5.1 Safety

Proper safety precautions must be observed when constructing and installing groundwater monitoring wells. Refer to the SESD Safety, Health and Environmental Management Program Procedures and Policy (SHEMP) Manual (Most Recent Version) and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines should be used to complement the judgment of an experienced professional. When using this procedure, minimize exposure to potential health hazards through the use of protective clothing, eye wear and gloves. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate. Section 2.6, Safety Procedures for Drilling Activities, contains detailed and specific safety guidelines that must be followed by Branch personnel when conducting activities related to monitoring well construction and installation.

1.5.2 Procedural Precautions

The following precautions should be considered when constructing and installing groundwater monitoring wells.

- Special care must be taken to minimize or prevent inadvertent cross-contamination between borehole locations. Equipment, tools and well materials must be cleaned and/or decontaminated according to procedures found in SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205).
- All field activities are documented in a bound logbook according to the procedures found in SESD Operating Procedure for Logbooks (SESDPROC-010).

2 Permanent Monitoring Well Design Considerations

2.1 General

The design and installation of permanent monitoring wells involves drilling into various types of geologic formations that exhibit varying subsurface conditions. Designing and installing permanent monitoring wells in these geologic environments may require several different drilling methods and installation procedures. The selection of drilling methods and installation procedures should be based on field data collected during a hydrogeologic site investigation and/or a search of existing data. Each permanent monitoring well should be designed and installed to function properly throughout the duration of the monitoring program. When designing monitoring wells, the following should be considered:

- Short-and long-term objectives;
- Purpose of the well(s);
- Probable duration of the monitoring program;
- Contaminants likely to be monitored;
- Surface and subsurface geologic conditions;
- Properties of the aquifer(s) to be monitored;
- Well screen placement;
- General site conditions; and
- Potential site health and safety hazards.

In designing permanent monitoring wells, the most reliable, obtainable data should be utilized. Once the data have been assembled and the well design(s) completed, a drilling method(s) must be selected. The preferred drilling methods for installing monitoring wells are those that temporarily case the borehole during drilling and the construction of the well, e.g. hollow-stem augers and sonic methods. However, site conditions or project criteria may not allow using these methods. When this occurs, alternate methods should be selected that will achieve the project objectives. The following discussion of methods and procedures for designing and installing monitoring wells will cover the different aspects of selecting materials and methods, drilling boreholes, and installing monitoring devices.

2.2 Drilling Methods

The following drilling methods may be used to install environmental monitoring wells or collect samples under various subsurface conditions. In all cases the preferred methods are those that case the hole during drilling, i.e. Hollow Stem Augers (HSA) and sonic methods using an override system. Other methods may be used where specific subsurface or project criteria dictate.

2.2.1 Hollow Stem Auger (HSA)

This type of auger consists of a hollow, steel stem or shaft with a continuous, spiraled steel flight, welded onto the exterior. A hollow auger bit, generally with carbide teeth, disturbs soil material when rotated, whereupon the spiral flights transport the cuttings to the surface. This method is best suited in soils that have a tendency to collapse when disturbed. A monitoring well can be installed inside of hollow-stem augers with little or no concern for the caving potential of the soils. If caving sands exist during monitoring well installations, a drilling rig must be used that has enough power to extract the augers from the borehole without having to rotate them. A bottom plug, trap door, or pilot bit assembly can be used at the bottom of the augers to keep out most of the soils and/or water that have a tendency to enter the bottom of the augers during drilling. Potable water (analyzed for contaminants of concern) may be poured into the augers during drilling to equalize pressure so that the inflow of formation materials will be held to a minimum. Water-tight center bits are not acceptable because they create suction when extracted from the augers. This suction forces or pulls cuttings and formation materials into the augers, defeating the purpose of the center plug. Augering without a center plug or pilot bit assembly is permitted, provided that the soil plug, formed in the bottom of the augers, is removed before sampling or installing well casings. Removing the soil plug from the augers can be accomplished by drilling and washing out the plug using a rotary bit, or augering out the plug with a solid-stem auger bit sized to fit inside the hollow-stem auger. Bottom plugs can be used where no soil sampling is conducted during the drilling process. The bottom plug is wedged into the bottom of the auger bit and is knocked out at depth with drill pipe or the weight of the casing and screen assembly. The plug material should be compatible with the screen and casing materials. The use of wood bottom plugs is not acceptable. The type of bottom plug, trap door, or pilot bit assembly proposed for the drilling activity should be approved by a senior field geologist prior to drilling operations. Boreholes can be augered to depths of 150 feet or more (depending on the auger size), but generally boreholes are augered to depths less than 100 feet.

2.2.2 Solid Stem Auger

This type of auger consists of a sealed hollow or solid stem or shaft with a continuous spiraled steel flight welded on the outside of the stem. An auger bit connected to the bottom disturbs soil material when rotated and the helical flights transport cuttings to the surface. At the desired depth the entire auger string is removed to gain access to the bottom of the borehole. This auger method is used in cohesive and semi-cohesive soils that do not have a tendency to collapse when disturbed. Boreholes can be augered to depths of 200 feet or more (depending on the auger size), but generally boreholes are augered to depths less than 100 feet.

Both of the previously discussed auger methods can be used in unconsolidated soils and semi-consolidated (weathered rock) soils, but not in competent rock.

Each method can be employed without introducing foreign materials into the borehole such as water and drilling fluids, minimizing the potential for cross contamination. Minimizing the risk of cross contamination is one of the most important factors to consider when selecting the appropriate drilling method(s) for a project.

2.2.3 Sonic Methods

These methods generally alternately advance concentric hollow drill stems using rotation in conjunction with axial vibration of the drill stem. After each stage of drill stem advancement, the inner string is removed with a core of drill cuttings while the outer 'override' string remains to hold the borehole open. The cuttings can be removed nearly intact from the inner casing for examination of the stratigraphy prior to sampling or disposal. Because there are no auger flights to increase the borehole diameter, the quantity of cuttings removed from the hole is minimized as compared to hollow stem augering. With moderate rotation, smearing of the formation materials on the borehole walls is reduced as well. This drilling method is useful in a variety of materials, from flowing sands to heavily consolidated or indurated formations.

In flowing sands, the drill casings can be filled and/or pressurized with potable water to prevent excess entry of formation materials into the drill string. The same QA/QC requirements for sampling of material introduced to the borehole apply as in other drilling methods. Because the amount of water introduced into the borehole can be significant, an approximation of the water used in the drilling process should be logged for use in estimating appropriate well development withdrawal.

Sonic drilling allows a larger diameter temporary casing to be set into a confining layer while drilling proceeds into deeper aquifers. This temporary casing is then removed during the grouting operation. In many cases this will be acceptable technique. However, the level of contamination in the upper aquifer, the importance of the lower aquifers for drinking water uses, the permeability and continuity of the confining layer, and state regulations should be taken into account when specifying this practice as opposed to permanent outer casing placed into the confining unit. Note that when using the temporary casing practice, it is critical that grout be mixed and placed properly as specified elsewhere in this section.

Because the total borehole diameter in sonic drilling is only incrementally larger than the inner casing diameter, particular care should be taken that the well casing is placed in the center of the drill stem while placing the filter pack. Centralizers should be used in most cases to facilitate centering, particularly in the case of deep wells with PVC casing.

2.2.4 Rotary Methods

These methods consist of a drill pipe or drill stem coupled to a drilling bit that rotates and cuts through the soils. The cuttings produced from the rotation of the drilling bit are transported to the surface by drilling fluids which generally consist of water, drilling mud, or air. The water, drilling mud, or air are forced down through the drill pipe, and out through the bottom of the drilling bit. The cuttings are then lifted to the surface between the borehole wall and the drill pipe, (or within a concentric drill stem in reverse rotary). Except in the case of air rotary, the drilling fluid provides a hydrostatic pressure that reduces or prevents borehole collapse. When considering this method, it is important to evaluate the potential for contamination when fluids and/or air are introduced into the borehole.

Due to the introduction of the various circulating fluids, the use of rotary methods requires that the potential for contamination by these fluids be evaluated. Water and mud rotary methods present the possibility of trace contamination of halogenated compounds when municipal water supplies are used as a potable water source. Air rotary drilling can introduce contamination through the use of lubricants or entrained material in the air stream. Unless contaminated formations are cased off, the circulation of drilling fluids presents a danger of cross contamination between formations. In any of the rotary (or sonic) methods, care must be exercised in the selection and use of compounds to prevent galling of drill stem threads.

2.2.4.1 Water Rotary

When using water rotary, potable water (that has been analyzed for contaminants of concern) should be used. If potable water (or a higher-quality water) is not available on-site, then potable water will have to be transported to the site or an alternative drilling method will have to be selected. Water does not clog the formation materials, but the suspended drilling fines can be carried into the formation, resulting in a very difficult to develop well. This method is most appropriate for setting isolation casing.

2.2.4.2 Air Rotary

Air rotary drilling uses air as a drilling fluid to entrain cuttings and carry them to the surface. High air velocities, and consequently large air volumes and compressor horsepower are required. “Down-the-hole” (DTH) percussion hammers driven by the air stream can be used with this method to rapidly penetrate bedrock materials. Where a casing through unconsolidated material is required to prevent borehole collapse, it can be driven in conjunction with advancement of the drill stem.

When using air rotary drilling in any zone of potential contamination, the cuttings exiting the borehole must be controlled. This can be done using the dual-tube reverse circulation method where cuttings are carried to the surface inside dual-wall drill pipe and separated with a cyclone separator. An air diverter with hose or pipe carrying cuttings to a waste container is also an acceptable alternative. Allowing cuttings to blow uncontrolled from the borehole is not acceptable.

When using air rotary, the issue of contaminants being introduced into the borehole by the air stream must be addressed. Screw compressor systems should have a coalescing filter system in good working order to capture excess entrained compressor oils. The lubricant to be used with DTH hammers as well as thread lubricants to be used on drill stem should be evaluated for their potential impact on analytical samples.

2.2.4.3 Mud Rotary

Mud rotary is an undesirable drilling method because contamination can be introduced into the borehole from the constituents in the drilling mud, cross contamination can occur along the borehole column, and it is difficult to remove the drilling mud from the borehole after drilling and during well development. The drilling mud can also carry contaminates from a contaminated zone to an uncontaminated zone thereby cross-contaminating the borehole. If mud rotary is selected, only potable water and pure (no additives) bentonite drilling muds should be used. All materials used should have adequate documentation as to manufacturer's recommendations and product constituents. QA/QC samples of drilling muds and potable water should be sampled at a point of discharge from the circulation system to assure that pumps and piping systems are not contributing cross-contamination from previous use.

2.2.5 Other Methods

Other methods such as the cable-tool method, jetting method, and boring (bucket auger) method are available. If these and/or other methods are selected for monitoring well installations, they should be approved by a senior field geologist before field work is initiated.

2.3 Borehole Construction

2.3.1 Annular Space

The borehole or hollow stem auger should be of sufficient diameter so that well construction can proceed without major difficulties. For open boreholes, the annular space should be approximately 2" to allow the uniform deposition of well materials around the screen and riser, and to allow the passage of tremie pipes and well materials without unduly disturbing the borehole wall. For example, a 2" nominal diameter (nom.) casing would require a 6" inside diameter (ID) borehole.

In hollow stem augers and sonic method drill casing, the ID should be of sufficient size to allow the passage of the tremie pipe to be used for well grout placement, as well as free passage of filter sands or bentonite pellets dropped through the auger or casing. In general, 4-1/4" ID should be the minimum size used for placement of 2" nom. casing and 8-1/4" ID for 4" nom. casing. Larger augers should be used where installation difficulties due to geologic conditions or greater depths are anticipated, e.g. larger augers might be required to place a bentonite pellet seal through a long water column.

2.3.2 Over-drilling the Borehole

Sometimes it is necessary to over-drill the borehole in anticipation of material entering the augers during center bit removal or knocking out of the bottom plug. Normally, 3 to 5 feet is sufficient for over-drilling. The borehole can also be over-drilled to allow for an extra space or a "sump" area below the well screen. This "sump" area provides a space to attach a 5 or 10 foot section of well casing to the bottom of the well screen. The extra space or "sump" below the well screen serves as a catch basin or storage area for sediment that flows into the well and drops out of suspension. These "sumps" are added to the well screens when the wells are screened in aquifers that are naturally turbid and will not yield clear formation water (free of visible sediment) even after extensive development. The sediment can then be periodically pumped out of the "sump" preventing the well screen from clogging or "silting up". If the borehole is inadvertently drilled deeper than desired, it can be backfilled to the design depth with bentonite pellets, chips, or the filter sand that is to be used for the filter pack.

2.3.3 Filter Pack Placement

When placing the filter pack into the borehole, a minimum of 6-inches of the filter pack material should be placed under the bottom of the well screen to provide a firm base. Also, the filter pack should extend a minimum of 2-feet above the top of the well screen to allow for settling and to isolate the screened interval from the grouting material. In open boreholes, the filter pack should be placed by the tremie or positive displacement method. Placing the filter pack by pouring the sand into an open drill stem is acceptable with the use hollow stem augers, and other methods where the borehole is temporarily cased down to the filter pack.

2.3.4 Filter Pack Seal – Bentonite Pellet Seal (Plug)

Bentonite pellets consist of ground, dried bentonite compacted into pellets available in several sizes. Bentonite pellets are compressed to a bulk density of 70-80 lbs/ft^3 and hydrate to a 30% min. solids material. Where neat cement grouts are to be used, the placement of a bentonite pellet seal above the filter pack is mandatory to prevent the possibility of grout infiltration into the screened interval prior to setting. Bentonite chips or other sealing products should not be substituted in this application. Where bentonite grouts are to be used, the placement of a bentonite pellet seal is optional, but desirable.

Since bentonite pellets begin hydrating rapidly, they can be very difficult to place properly. They are generally placed by pouring slowly into open boreholes, hollow stem augers or sonic drill pipe. In some cases, pellets are placed by tremie pipe and flushed into place with potable water. A tamper can be used to ensure that the material is being placed properly and to rapidly break up any pellet bridging that occurs.

Pellet seals should be designed for a two-foot thickness of dry pellets above the filter pack. Hydration may extend the height of the seal. Where neat cement grouts are to be used, the pellets should be hydrated for eight hours, or the manufacturer's recommended hydration time, whichever is greater. Where the water table is temporarily below the pellet seal, potable (or higher quality) water should be added repeatedly to hydrate the pellets prior to grouting.

2.3.5 Grouting the Annular Space

The annular space between the casing and the borehole wall should be filled with either a 30% solids bentonite grout, a neat cement grout, or a cement/bentonite grout. Each type of grout selected should be evaluated as to its intended use and integrity. Bentonite grouts are preferred unless the application dictates the use of another material.

Bentonite grout shall be a 30% solids pure bentonite grout. Drilling muds are not acceptable for grouting. The grout should be placed into the borehole, by the tremie method, from the top of the bentonite seal to within 2-feet of the ground surface or below the frost line, whichever is the greater depth. The bentonite pellet seal or filter pack should not be disturbed during grout placement, either by the use of a side discharge port on the tremie tube, or by maintaining clearance between the bottom of the tremie tube and the bentonite seal or filter pack. The grout should be allowed to cure for a minimum of 24 hours before the concrete surface pad is installed. The preferred method of achieving proper solids content is by measurement of ingredients per the manufacturer's specifications during mixing with a final check by grout balance after mixing. Bentonite grouts should have a minimum density of 10 lbs/gal to ensure proper gelling and low permeability. The density of the first batch of grout should be measured while mixing to verify proper measurement of ingredients. In addition, the grouting operation should not cease until the bentonite grout flowing out of the borehole has a minimum density of 10 lbs/gal. Estimating the grout density is not acceptable.

Cement grouts are generally dictated where a high level of dissolved solids or a particular dissolved constituent would prevent proper gelling of a bentonite grout. Neat cement grouts (cement without additives) should be mixed using 6 gallons of water per 94-lb bag of Type 1 Portland cement to a density of 15lbs/gal. The addition of bentonite (5 to 10 percent) to the cement grout can be used to delay the "setting" time and may not be needed in all applications. The specific mixtures and other types of cement and/or grout proposed should be evaluated on a case by case basis by a senior field geologist.

2.3.6 Above Ground Riser Pipe and Outer Casing

The well casing, when installed and grouted, should extend above the ground surface a minimum of 2.5 feet. A vent hole should be drilled into the top of the well casing cap to permit pressure equalization, if applicable. An outer protective casing should be installed into the borehole after the annular grout has cured for at least 24 hours. The outer protective casing should be of steel construction with a hinged, locking cap. Generally, outer protective casings used over 2-inch well casings are 4 inches square by 5 feet long. Similarly, protective casings used over 4-inch well casings are 6 inches square and 5 feet long. Other types of protective casing including those constructed of pipe are also acceptable. All protective casings should have sufficient clearance around the inner well casings, so that the outer protective casings will not come into contact with the inner well casings after installation. The protective casings should have a weep hole to allow drainage of accumulated rain or spilled purge water. The weep hole should be approximately 1/4-inch in diameter and drilled into the protective casings just above the top of the concrete surface pad to prevent water from standing inside of the protective casings. Protective casings made of aluminum or other soft metals are normally not acceptable because they are not strong enough to resist tampering. Aluminum protective casing may be used in very corrosive environments such as coastal areas.

Prior to installing the protective casing, the bentonite grout in the borehole annulus is excavated to a depth of approximately two feet. The protective casing is installed by pouring concrete into the borehole on top of the grout. The protective casing is then pushed into the wet concrete and borehole a minimum of 2 feet. Extra concrete may be needed to fill the inside of the protective casing so that the level of the concrete inside of the protective casing is at or above the level of the surface pad. In areas where frost heave of the surface pad is possible, the protective casing should first be pressed into the top surface of the bentonite grout seal and concrete poured around the protective casing. A granular material such as sand or gravel can then be used to fill the space between the riser and protective casing. The use of granular material instead of concrete between the protective casing and riser will also facilitate the future conversion of the well to a flush-mount finish, if required. The protective casing should extend above the ground surface to a height so that the top of the inner well casing is exposed when the protective casing is opened. At each site, all locks on the outer protective casings should be keyed alike.

2.3.7 Concrete Surface Pad

A concrete surface pad should be installed around each well at the same time as the outer protective casing is being installed. The surface pad should be formed around the well casing. Concrete should be placed into the pad forms and into the borehole (on top of the grout) in one operation making a contiguous unit. The size of the concrete surface pad is dependent on the well casing size. If the well casing is 2 inches in diameter, the pad should be 3 feet x 3 feet x 4 inches. If the well casing is 4 inches in diameter, the pad should be 4 feet x 4 feet x 6 inches. Round concrete surface pads are also acceptable. The finished pad should be slightly sloped so that drainage will flow away from the protective casing and off of the pad. A minimum of one inch of the finished pad should be below grade to prevent washing and undermining by soil erosion.

2.3.8 Surface Protection – Bumper Guards

If the monitoring wells are located in a high traffic area, a minimum of three bumper guards consisting of steel pipes 3 to 4 inches in diameter and a minimum 5-foot length should be installed. These bumper guards should be installed to a minimum depth of 2 feet below the ground surface in a concrete footing and extend a minimum of 3 feet above ground surface. Concrete should also be placed into the steel pipe to provide additional strength. Substantial steel rails and/or other steel materials can be used in place of steel pipe. Welding bars between the bumper posts can provide additional strength and protection in high traffic areas, but the protective bumpers should not be connected to the protective casing.

2.4 Construction Techniques

2.4.1 Well Installation

The borehole should be bored, drilled, or augered as close to vertical as possible, and checked with a plumb bob or level. Deviation from plumb should be within 1° per 50ft of depth. Slanted boreholes are undesirable and should be noted in the boring logs and final construction logs. The depth and volume of the borehole, including the over-drilling if applicable, should have been calculated and the appropriate materials procured prior to drilling activities.

The well casings should be secured to the well screen by flush-jointed threads and placed into the borehole and plumbed by the use of centralizers and/or a plumb bob and level. Another method of placing the well screen and casings into the borehole and plumbing them at the same time is to suspend the string of well screen and casings in the borehole by means of a hoist on the drill rig. This wireline method is especially useful if the borehole is deep and a long string of well screen and casings have to be set and plumbed.

No lubricating oils or grease should be used on casing threads. No glue of any type should be used to secure casing joints. Teflon "O" rings can also be used to insure a tight fit and minimize leakage; however, "O" rings made of other materials are not acceptable if the well is going to be sampled for organic compound analyses.

Before the well screen and casings are placed on the bottom of the borehole, at least 6 inches of filter material should be placed at the bottom of the borehole to serve as a firm footing. The string of well screen and casings should then be placed into the borehole and plumbed. Centralizers can be used to plumb a well, but centralizers should be placed so that the placement of the filter pack, bentonite pellet seal, and annular grout will not be hindered. Centralizers placed in the wrong locations can cause bridging during material placement. Monitoring wells less than 50 feet deep generally do not need centralizers. If centralizers are used they should be placed below the well screen and above the bentonite pellet seal. The specific placement intervals should be decided based on site conditions.

When installing the well screen and casings through hollow-stem augers, the augers should be slowly extracted as the filter pack, bentonite pellet seal, and grout are tremied and/or poured into place. The gradual extraction of the augers will allow the materials being placed in the augers to flow out of the bottom of the augers into the borehole. If the augers are not gradually extracted, the materials (sand, pellets, etc.) will accumulate at the bottom of the augers causing potential bridging problems.

After the string of well screen and casing is plumb, the filter pack material should then be placed around the well screen to the designated depth. With cased drilling methods, the sand should be poured into the casing or augers until the lower portion is filled. The casing or augers are then withdrawn, allowing the sand to flow into the evacuated space. With hollow stem augers, sand should always fill the augers 6-12 inches, maintained by pouring the sand while checking the level with a weighted tag line. The filter pack sand in open boreholes should be installed by tremie methods, using water to wash the sand through the pipe to the point of placement.

After the filter pack has been installed, the bentonite pellet seal (if used) should be placed directly on top of the filter pack to an unhydrated thickness of two feet. When installing the seal for use with cement grouts, the bentonite pellet seal should be allowed to hydrate a minimum of eight hours or the manufacturer's recommended hydration time, whichever is longer.

After the pellet seal has hydrated for the specified time, the grout should then be pumped by the tremie method into the annular space around the casings. The grout should be allowed to set for a minimum of 24 hours before the surface pad and protective casing are installed.

After the surface pad and protective casing are installed, bumper guards should be installed (if needed). The bumper guards should be placed around the concrete surface pad in a configuration that provides maximum protection to the well. Each piece of steel pipe or approved material should be installed into an 8-to 10-inch diameter hole, to a minimum depth of 2 feet below ground surface, and filled with concrete. As previously stated, the bumper guard should extend above the ground surface a minimum of 3 feet. The total length of each bumper guard should be a minimum of 5 feet.

After the wells have been installed, the outer protective casing should be painted with a highly visible paint. The wells should be permanently marked with the well number, date installed, site name, elevation, etc., either on the cover or an appropriate place that will not be easily damaged and/or vandalized.

If the monitoring wells are installed in a high traffic area such as a parking lot, in a residential yard, or along the side of a road it may be desirable to finish the wells to the ground surface and install water-tight flush mounted traffic and/or man-hole covers. Flush mounted traffic and man-hole covers are designed to extend from the ground surface down into the concrete plug around the well casing. Although flush mounted covers may vary in design, they should have seals that make the unit water-tight when closed and secured. The flush mounted covers should be installed slightly above grade to minimize standing water and promote runoff. Permanent identification markings should be placed on the covers or in the concrete plug around the cover. Expansive sealing plugs should be used to cap the well riser to prevent infiltration of any water that might enter the flush cover.

2.4.2 Double-Cased Wells

Double-cased wells should be constructed when there is reason to believe that interconnection of two aquifers by well construction may cause cross-contamination or when flowing sands make it impossible to install a monitoring well using conventional methods. A highly contaminated surface soil zone may also be cased off so that drilling may continue below the casing with reduced danger of cross contamination. A pilot borehole should be bored through the overburden and/or the contaminated zone into the clay confining layer or bedrock. An outer casing (sometimes called surface or pilot casings) should then be placed into the borehole and sealed with grout. The borehole and outer casing should extend into tight clay a minimum of two feet and into competent bedrock a minimum of 1 foot. The total depths into the clay or bedrock will vary, depending on the plasticity of the clay and the extent of weathering and\or fracturing of the bedrock. The final depths should be approved by a senior field geologist. The size of the outer casing should be of sufficient inside diameter to contain the inner casing, and the 2-inch minimum annular space. In addition, the borehole should be of sufficient size to contain the outer casing and the 2-inch minimum outer annular space, if applicable.

The outer casing should be grouted by the tremie, displacement, grout shoe, or Halliburton method from the bottom to the ground surface. The grout should be pumped into the annular space between the outer casing and the borehole wall. A minimum of 24 hours should be allowed for the grout plug (seal) to cure before attempting to drill through it. The grout mixture used to seal the outer annular space should be either a neat cement, cement/bentonite, cement/sand, or a 30% solids bentonite grout. However, the seal or plug at the bottom of the borehole and outer casing should consist of a Type I portland cement/bentonite or cement/sand mixture. The use of a pure bentonite grout for a bottom plug or seal is not acceptable, because the bentonite grout cures to a gel-like material, and is not rigid enough to withstand the stresses of drilling. When drilling through the seal, care should be taken to avoid cracking, shattering, or washing out the seal. If caving conditions exist so that the outer casing cannot be sufficiently sealed by grouting, the outer casing should be driven into place and a grout seal placed in the bottom of the casing.

2.4.2.1 Bedrock Wells

The installation of monitoring wells into bedrock can be accomplished in two ways:

1. The first method is to drill or bore a pilot borehole through the soil overburden into the bedrock. An outer casing is then installed into the borehole by setting it into the bedrock, and grouting it into place as described in the previous section. After the grout has set, the borehole can then be advanced through the grout seal into the bedrock. The preferred method of advancing the borehole into the bedrock is rock coring. Rock coring makes a smooth, round hole through the seal and into the bedrock without cracking and/or shattering the seal. Roller cone bits are used in soft bedrock, but extreme caution should be taken when using a roller cone bit to advance through the grout seal in the bottom of the borehole because excessive water and "down" pressure can cause cracking, eroding (washing), and/or shattering of the seal. Low volume air hammers may be used to advance the borehole, but they have a tendency to shatter the seal because of the hammering action. If the structural integrity of the grout seal is in question, a pressure test can be utilized to check for leaks. A visual test can also be made by examining the cement/concrete core that is collected when the seal is cored with a diamond coring bit. If the seal leaks (detected by pressure testing) and/ or the core is cracked or shattered, or if no core is recovered because of washing, excessive down pressure, etc., the seal is not acceptable. The concern over the structural integrity of the grout seal applies to all double cased wells. Any proposed method of double casing and/or seal testing will be evaluated on its own merits, and will have to be approved by a senior field geologist before and during drilling activities, if

applicable. When the drilling is complete, the finished well will consist of an open borehole from the ground surface to the bottom of the well. There is no inner casing, and the outer surface casing, installed down into bedrock, extends above the ground surface, and also serves as the outer protective casing. If the protective casing becomes cracked or is sheared off at the ground surface, the well is open to direct contamination from the ground surface and will have to be repaired immediately or abandoned. Another limitation to the open rock well is that the entire bedrock interval serves as the monitoring zone. In this situation, it is very difficult or even impossible to monitor a specific zone, because the contaminants being monitored could be diluted to the extent of being non-detectable. The installation of open bedrock wells is generally not acceptable in the Superfund and RCRA programs, because of the uncontrolled monitoring intervals. However, some site conditions might exist, especially in cavernous limestone areas (karst topography) or in areas of highly fractured bedrock, where the installation of the filter pack and its structural integrity are questionable. Under these conditions the design of an open bedrock well may be warranted.

2. The second method of installing a monitoring well into bedrock is to install the outer surface casing and drill the borehole (by an approved method) into bedrock, and then install an inner casing and well screen with the filter pack, bentonite seal, and annular grout. The well is completed with a surface protective casing and concrete pad. This well installation method gives the flexibility of isolating the monitoring zone(s) and minimizing inter-aquifer flow. In addition, it gives structural integrity to the well, especially in unstable areas (steeply dipping shales, etc.) where the bedrock has a tendency to shift or move when disturbed. Omitting the filter pack around the well screen is a general practice in some open rock borehole installations, especially in drinking water and irrigation wells. However, without the filter pack to protect the screened interval, sediment particles from the well installation and/or from the monitoring zone could clog the well screen and/or fill the screened portion of the well rendering it inoperable. Also, the filter pack serves as a barrier between the bentonite seal and the screened interval. Rubber inflatable packers have been used to place the bentonite seal when the filter pack is omitted, but the packers have to remain in the well permanently and, over a period of time, will decompose and possibly contribute contaminants to the monitoring zone.

2.5 Well Construction Materials

2.5.1 Introduction

Well construction materials are chosen based on the goals and objectives of the proposed monitoring program and the geologic conditions at the site(s). In this section, the different types of available materials will be discussed.

2.5.2 Well Screen and Casing Materials

When selecting the materials for well construction, the prime concern should be to select materials that will not contribute foreign constituents, or remove contaminants of concern from the ground water. If the monitoring program is designed to analyze for organic compounds, stainless steel materials are the preferred choice. If the monitoring program calls for the analyses of only inorganic compounds or the contaminants or formation are highly corrosive, then rigid PVC materials meeting National Sanitary Foundation (NSF) Standard 14 type WC (Well Casing) are acceptable. PVC materials may be acceptable for monitoring identified organic compounds in a soluble aqueous phase where incompatibilities are known to not exist. EPA document EPA/540/S-95/503, *Nonaqueous Phase Liquids Compatibility with Materials Used in Well Construction, Sampling, and Remediation* (http://www.epa.gov/ada/-download/issue/napl.pdf) should be used for guidance in this area and in the use of PVC with non-aqueous phase liquids (NAPLs). Another concern is to select materials that will be rugged enough to endure the entire monitoring period. Site conditions will generally dictate the type of materials that can be used. A preliminary field investigation should be conducted to determine the geologic conditions, so that the most suitable materials can be selected. The best grade or highest quality material for that particular application should be selected. Each manufacturer can supply the qualitative data for each grade of material that is being considered. All materials selected for monitoring well installation should be evaluated and approved by a senior field geologist prior to field activities.

Well screen and casing materials generally used in monitoring well construction on RCRA and Superfund sites are listed in order of preference:

1. Stainless Steel (304 or 316)
2. Rigid PVC meeting NSF Standard 14 (type WC)
3. Other (where applicable)

There are other materials used for well screens and casings such as black iron, carbon steel, galvanized steel, and fiberglass, but these materials are not recommended for use in long term monitoring programs at hazardous waste sites, because of their low resistance to chemical attack and potential constituent contribution to the ground water. In cases where a driven casing is used, or a high strength outer casing is needed, carbon steel may be acceptable in non-corrosive aquifers. This outer casing should have threaded connections. Welding casing is not an acceptable practice unless all relevant safety issues have been adequately addressed.

The minimum nominal casing size for most permanent monitoring wells will be 2". Where a complete program of installation, monitoring, and abandonment is being designed, smaller wells may be installed if suitable purging and sampling equipment for the smaller diameter wells can be specified and obtained. The length of well screens in permanent monitoring wells should be long enough to effectively monitor the interval or zone of interest. However, well screens designed for long term monitoring purposes should normally not be less than 5 feet in length. Well screens less than 5 feet long are generally only used in temporary monitoring wells where ground water samples are collected for screening purposes.

2.5.3 Filter Pack Materials

The filter pack materials should consist of clean, rounded to well-rounded, hard, insoluble particles of siliceous composition. The required grain-size distribution or particle sizes of the filter pack materials should be selected based upon a sieve analysis conducted on the soil samples collected from the aquifer materials and/or the formation(s) to be monitored. Filter pack materials should not be accepted unless proper documentation can be furnished as to the composition, grain-size distribution, cleaning procedure, and chemical analysis. If a data search reveals that there is enough existing data to adequately design the well screen and filter pack, then it may not be necessary to conduct a sieve analysis on the formation materials to be monitored. However, all data and design proposals will be evaluated and approved by a senior staff geologist before field activities begin.

2.5.4 Filter Pack and Well Screen Design

The majority of monitoring wells are installed in shallow ground water aquifers that consist of silts, clays, and sands in various combinations. These shallow aquifers are not generally characteristic of aquifers used for drinking water. Therefore, modifications to the procedures used for the design of water well filter packs may be required. In cases where insufficient experience exists with local or similar materials, the filter pack and well screen design should be based on the results of a sieve analysis conducted on soil samples collected from the aquifer or the formation(s) that will be monitored.

In formations consisting primarily of fines (silts and clays), the procedures for water well screen design may result in requirements for filter packs and screen slot sizes that are not available. In those cases the selection of 0.010" screen slots with a 20-40 sand filter pack, or 0.005" screen slots with 100 sand filter pack for very fine formations, will be acceptable practice. Table 6.6.1 provides size specifications for the selection of sand packs for fine formation materials. ASTM standard D5092, *Design and Installation of Ground Water Monitoring Wells in*

Aquifers, may be consulted for further guidance on specifications for sand appropriate for these applications.

Table 6.6.1
Sand Pack Specifications

Screen Opening (in)	Sand Pack Mesh Name	1% Passing Size (d-1) (in)	10% Passing Size (d-10) (in)	30% Passing Size (d-30) (in)	Derived 60% Passing Size (d-60) (in)	Range for Uniformity Coefficient
0.005-0.006	100	.0035 - .0047	.0055 - .0067	.0067 - .0083	.0085 - .0134	1.3 - 2.0
0.010"	20-40	.0098 - .0138	.0157 - .0197	.0197 -.0236	.020 - .0315	1.1 - 1.6

The following procedure should be used in coarser grained formations:

The data from the sieve analysis are plotted on a grain-size distribution graph, and a grain-size distribution curve is generated. From this grain-size distribution curve, the uniformity coefficient (Cu) of the aquifer material is determined. The Cu is the ratio of the 60 percent finer material (d60) to the 10 percent finer material (d10)

$$Cu = (d60/d10)$$

The Cu ratio is a way of grading or rating the uniformity of grain size. For example, a Cu of unity means that the individual grain sizes of the material are nearly all the same, while a Cu with a large number indicates a large range of particle sizes. As a general rule, a Cu of 2.5 or less should be used in designing the filter pack and well screen.

Before designing the filter pack and well screen, the following factors should be considered:

1. Select the well screen slot openings that will retain 90 percent of the filter pack material.

2. The filter pack material should be of the size that minimizes head losses through the pack and also prevents excessive sediment (sand, silt, clay) movement into the well.

3. A filter material of varying grain sizes is not acceptable because the smaller particles fill the spaces between the larger particles thereby reducing the void spaces and increasing resistance to flow. Therefore, filter material of the same grain size and well rounded is preferred.

4. The filter pack design is based on the gradation of the finest aquifer materials being analyzed.

Steps to design a filter pack in aquifers:

1. Construct a grain-size distribution curve, on a grain-size distribution graph, from the sieve analysis of the aquifer materials. The filter pack design (as stated above) is based on the gradation of the finest aquifer materials.

2. Multiply the d30 size from the grain-size distribution graph by a factor of four to nine (Pack-Aquifer ratio). A factor of four is used if the formation is fine-grained and uniform (Cu is less than 3), six if it is coarse-grained and non-uniform, and up to nine if it is highly non-uniform and contains silt. Head losses through filter packs increase as the Pack-Aquifer (P-A) ratios decrease. In order to design a fairly stable filter pack with a minimum head loss, the d30 size should be multiplied by a factor of four.

3. Plot the point from step 2 on the d30 abscissa of a grain-size distribution graph and draw a smooth curve with a uniformity coefficient of approximately 2.5.

4. A curve for the permissible limits of the filter pack is drawn plus or minus 8 per cent of the desired curve with the Cu of 2.5.

5. Select the slot openings for the well screen that will retain 90 per cent or more of the filter pack material.

The specific steps and procedures for sieve analysis and filter pack design can be found in soil mechanics, ground water, and water well design books. The staff geologists and/or engineers should be responsible for the correct design of the monitoring wells and should be able to perform the design procedures.

2.6 Safety Procedures for Drilling Activities

A site health and safety plan should be developed and approved by the Branch Safety Officer or designee prior to any drilling activities, and should be followed during all drilling activities. The driller or designated safety person should be responsible for the safety of the drilling team performing the drilling activities. All personnel conducting drilling activities should be qualified in proper drilling and safety procedures. Before any drilling activity is initiated, utilities should be marked or cleared by the appropriate state or municipal utility protection organization. In developed areas, additional measures should be taken to locate utilities not covered by the utility protection program. Before operating the drill rig, a pilot hole should be dug (with hand equipment) to a depth of three feet to check for undetected utilities or buried objects. Proceed with caution until a safe depth is reached where utilities normally would not be buried. The following safety requirements should be adhered to while performing drilling activities:

1. All drilling personnel should wear safety hats, safety glasses, and steel toed boots. Ear plugs are required and will be provided by the safety officer or driller.

2. Work gloves (cotton, leather, etc.) should be worn when working around or while handling drilling equipment.

3. All personnel directly involved with the drilling rig(s) should know where the kill switch(s) is located in case of emergencies.

4. All personnel should stay clear of the drill rods or augers while in motion, and should not grab or attempt to attach a tool to the drill rods or augers until they have completely stopped rotating. Rod wipers, rather than gloves or bare hands should be used to remove mud, or other material, from drill stem as it is withdrawn from the borehole.

5. Do not hold drill rods or any part of the safety hammer assembly while taking standard penetration tests or while the hammer is being operated.

6. Do not lean against the drill rig or place hands on or near moving parts at the rear of the rig while it is operating.

7. Keep the drilling area clear of any excess debris, tools, or drilling equipment.

8. The driller will direct all drilling activities. No work on the rig or work on the drill site will be conducted outside of the driller's direction. Overall drill site activities will be in consultation with the site geologist or engineer, if present.

9. Each drill rig will have a first-aid kit and a fire extinguisher located on the rig in a location quickly accessible for emergencies. All drilling personnel will be familiarized with their location.

10. Work clothes will be firm fitting, but comfortable and free of straps, loose ends, strings etc., that might catch on some moving part of the drill rig.

11. Rings, watches, or other jewelry will not be worn while working around the drill rig.

12. The drill rig should not be operated within a minimum distance of 20 feet of overhead electrical power lines and/or buried utilities that might cause a safety hazard. In addition, the drill rig should not be operated while there is lightening in the area of the drilling site. If an electrical storm moves in during drilling activities, the area will be vacated until it is safe to return.

2.7 Well Development

A newly completed monitoring well should not be developed for at least 24 hours after the surface pad and outer protective casing are installed. This will allow sufficient time for the well materials to cure before development procedures are initiated. The main purpose of developing new monitoring wells is to remove the residual materials remaining in the wells after installation has been completed, and to try to re-establish the natural hydraulic flow conditions of the formations which may have been disturbed by well construction, around the immediate vicinity of each well. A new monitoring well should be developed until the column of water in the well is free of visible sediment, and the pH, temperature, turbidity, and specific conductivity have stabilized. In most cases the above requirements can be satisfied; however, in some cases the pH, temperature, and specific conductivity may stabilize but the water remains turbid. In this case the well may still contain well construction materials, such as drilling mud in the form of a mud cake and/or formation soils that have not been washed out of the borehole. Excessive or thick drilling mud cannot be flushed out of a borehole with one or two well volumes of flushing. Continuous flushing over a period of several days may be necessary to complete the well development. If the well is pumped to dryness or near dryness, the water table should be allowed to sufficiently recover (to the static water level) before the next development period is initiated. Caution should be taken when using high rate pumps and/or large volume air compressors during well development because excessive high rate pumping and high air pressures can damage or destroy the well screen and filter pack. The onsite geologist should make the decision as to the development completion of each well. All field decisions should be documented in the field log book.

The following development procedures, listed in approximate increasing order of the energy applied to the formation materials, are generally used to develop wells:

1. Bailing
2. Pumping/overpumping
3. Surging
4. Backwashing ("rawhiding")
5. Jetting
6. Compressed air (with appropriate filtering): airlift pumping and air surging

These development procedures can be used, individually or in combination, in order to achieve the most effective well development. In most cases, over-pumping and surging will adequately develop the well without imparting undue forces on the formation or well materials. Except when compressed air is being used for well development, sampling can be initiated as soon as the ground water has re-equilibrated, is free of visible sediment, and the water quality parameters have stabilized. Since site conditions vary, even between wells, a general rule-of-thumb is to wait 24 hours after development to sample a new monitoring well. Wells developed with stressful measures may require as long as a 7-day interval before sampling. In particular, air surge developed wells require 48 hours or longer after development so that the formation can dispel the compressed air and re-stabilize to pre-well construction conditions. Because of the danger of introducing contaminants with the airstream, the possibility of entraining air in the aquifer, and the violent forces imparted to the formation, air surging is the least desired method of development and should only be used where there is a specific need for the procedure. Air-lift pumping is permissible where an eductor pipe is used and several well volumes of water are removed from the well by other by pumping means after air-lift pumping. The selected development method(s) should be approved by a senior field geologist before any well installation activities are initiated.

2.8 Well Decommisioning (Abandonment)

When a decision is made to decommission (abandon) a monitoring well, the borehole should be sealed in such a manner that the well cannot act as a conduit for migration of contaminants from the ground surface to the water table or between aquifers. To properly decommission a well, the preferred method is to completely remove the well casing and screen from the borehole, clean out the borehole, and backfill with a cement or bentonite grout, neat cement, or concrete. In order to comply with state well decommissioning requirements, the appropriate state agency should be notified (if applicable) of monitoring well decommissioning. However, some state requirements are not explicit, so a technically sound well abandonment method should be designed based on the site geology, well casing materials, and general condition of the well(s).

2.8.1 Decommissioning Procedures

As previously stated the preferred method should be to completely remove the well casing and screen from the borehole. This may be accomplished by augering with a hollow-stem auger over the well casing down to the bottom of the borehole, thereby removing the grout and filter pack materials from the hole. The well casing should then be removed from the hole with the drill rig. The clean borehole can then be backfilled with the appropriate grout material. The backfill material should be placed into the borehole from the bottom to the top by pressure grouting with the positive displacement method (tremie method). This abandonment method can be accomplished on small diameter (1-inch to 4-inch) wells without too much difficulty. With wells having 6-inch or larger diameters, the use of hollow-stem augers for casing removal is very difficult or almost impossible. Instead of trying to ream the borehole with a hollow-stem auger, it is more practical to force a drill stem with a tapered wedge assembly or a solid-stem auger into the well casing and extract it out of the borehole. Wells with little or no grouted annular space and/or sound well casings can be removed in this manner. However, old wells with badly corroded casings and/or thickly grouted annular space have a tendency to twist and/or break-off in the borehole. When this occurs, the well will have to be grouted with the remaining casing left in the borehole. The preferred method in this case should be to pressure grout the borehole by placing the tremie tube to the bottom of the well casing, which will be the well screen or the bottom sump area below the well screen. The pressurized grout will be forced out through the well screen into the filter material and up the inside of the well casing sealing holes and breaks that are present.

A PVC well casing may be more difficult to remove from the borehole than a metal casing, because of its brittleness. If the PVC well casing breaks during removal, the borehole should be cleaned out by using a drag bit or roller cone bit with the wet rotary method to grind the casing into small cuttings that will be flushed out of the borehole by water or drilling mud. Another method is to use a solid-stem auger with a carbide tooth pilot bit to grind the PVC casing into small cuttings that will be brought to the surface on the rotating flights. After the casing materials have been removed from the borehole, the borehole should be cleaned out and pressure grouted with the approved grouting materials.

Where state regulations and conditions permit, it may be permissible to grout the casing in place. This decision should be based on confidence in the original well construction practice, protection of drinking water aquifers, and anticipated future property uses. The pad should be demolished and the area around the casing excavated. The casing should be sawn off at a depth of three feet below ground surface. The screen and riser should be tremie grouted with a 30% solids bentonite grout in the saturated zone. The remaining riser may be grouted with a cement grout for long term resistance to desiccation.

3 Temporary Monitoring Well Installation

3.1 Introduction

Five types of temporary monitoring well installation techniques have been demonstrated as acceptable. The type selected for a particular site is dependent upon site conditions. The project leader and site geologist should be prepared to test temporary well installations on site and select the best solution. Temporary wells are cost effective, may be installed quickly, and provide a synoptic picture of ground water quality.

Temporary monitoring well locations are not permanently marked, nor are their elevations normally determined. Sand pack materials may or may not be used, but typically there is no bentonite seal, grout, surface completion, or extensive development (as it normally applies to permanent monitoring wells). Temporary wells are generally installed, purged, sampled, removed, and backfilled in a matter of hours.

Due to the nature of construction, turbidity levels may initially be high. However, these levels may be reduced by low flow purging and sampling techniques as described in Section 7.2.4.

Temporary wells may be left overnight, for sampling the following day, but the well must be secured, both against tampering and against the fall hazard of the open annulus. If the well is not sampled immediately after construction, the well should be purged prior to sampling as specified in SESD Operating Procedure for Groundwater Sampling, SESDPROC-301.

3.2 Data Limitation

Temporary wells described in this section are best used for delineation of contaminant plumes at a point in time, and for some site screening purposes. They are not intended to replace permanent monitoring wells. Temporary wells can be used in conjunction with a mobile laboratory, where quick analytical results can be used to delineate contaminant plumes.

3.3 Temporary Well Materials

Materials used in construction of temporary monitoring wells are the same standard materials used in the construction of permanent monitoring wells. Sand used for the filter pack (if any) should be as specified in Section 2.5.3, Filter Pack Materials. The well screen and casing should be stainless steel for ruggedness and suitability for steam cleaning and solvent rinsing. Other materials may be acceptable, on a case by case basis. Some commercially available temporary well materials, pre-packed riser, screen and filter pack assemblies are available commercially; however, these pre-assembled materials cannot be cleaned. Appropriate QA/QC must be performed to assure there will be no introduction of contamination.

3.4 Temporary Monitoring Well Borehole Construction

Borehole construction for temporary wells is as specified in Section 2.3, using a drill rig. Alternatively, boreholes may be constructed using hand augers or portable powered augers (generally limited to depths of ten feet or less). If a drill rig is used to advance the borehole, the augers must be pulled back the length of the well screen (or removed completely) prior to sampling. When hand augers are used, the borehole is advanced to the desired depth (or to the point where borehole collapse occurs). In situations where borehole collapse occurs, the auger bucket is typically left in the hole at the point of collapse while the temporary well is assembled. When the well is completely assembled, a final auger bucket of material is quickly removed and the well is immediately inserted into the borehole, pushing, as needed, to achieve maximum penetration into the saturated materials.

3.5 Temporary Monitoring Well Types

Five types of monitoring wells which have been shown to be acceptable are presented in the order of increasing difficulty to install and increasing cost:

3.5.1 No Filter Pack

This is the most common temporary well and is very effective in many situations. After the borehole is completed, the casing and screen are simply inserted. This is the least expensive and fastest well to install. This type of well is extremely sensitive to turbidity fluctuations because there is no filter pack. Care should be taken to not disturb the casing during purging and sampling.

3.5.2 Inner Filter Pack

This type differs from the "No Filter Pack" well in that a filter pack is placed inside the screen to a level approximately 6 inches above the well screen. This ensures that all water within the casing has passed through the filter pack. For this type well to function properly, the static water level must be at least 6-12 inches above the filter pack. The screen slots may plug in some clayey environments with this construction method and others that use sand only inside the well screen.

3.5.3 Traditional Filter Pack

For this type of well, the screen and casing are inserted into the borehole, and the sand is poured into the annular space surrounding the screen and casing. Occasionally, it may be difficult to effectively place a filter pack around shallow open boreholes, due to collapse. This method requires more sand than the "inner filter pack" well, increasing material costs. As the filter pack is placed, it mixes with the muddy water in the borehole, which may increase the amount of time needed to purge the well to an acceptable level of turbidity.

3.5.4 Double Filter Pack

The borehole is advanced to the desired depth. As with the "inner filter pack" the well screen is filled with filter pack material and the well screen and casing inserted until the top of the filter pack is at least 6 inches below the water table. Filter pack material is poured into the annular space around the well screen. This type temporary well construction can be effective in aquifers where fine silts or clays predominate. This construction technique takes longer to implement and uses more filter pack material than others previously discussed.

3.5.5 Well-in-a-Well

The borehole is advanced to the desired depth. At this point, a 1-inch well screen and sufficient riser is inserted into a 2-inch well screen with sufficient riser, and centered. Filter pack material is then placed into the annular space surrounding the 1-inch well screen, to approximately 6 inches above the screen. The well is then inserted into the borehole.

This system requires twice as much well screen and riser, with attendant increases in assembly and installation time. The increased amount of well construction materials results in a corresponding increase in decontamination time and costs. The use of pre-packed well screens in this application will require rinse blanks of each batch of screens. Pre-pack Screen assemblies cannot be decontaminated for reuse.

3.6 Decommissioning

Temporary well boreholes must be decommissioned after sampling and removal of the screen and riser. Backfilling the holes with cuttings may be acceptable practice for shallow holes in uniform materials with expected low contamination levels. Use of cuttings would not be an acceptable practice if waste materials were encountered or a confining layer was breached. Likewise, where the borehole is adjacent to, or downgradient of contaminated areas, the loose backfilled material could create a highly permeable conduit for contaminant migration. If the borehole will not be backfilled with the soil cuttings for this or other reasons, then SESD Operating Procedure for Management of Investigation Derived Waste, SESDPROC-202, should be referenced regarding disposal of the cuttings as IDW.

4 Temporary Monitoring Well Installation Using the Geoprobe® Screen Point 15/16 Groundwater Sampler

4.1 Introduction

The Geoprobe® Screen Point 15/16 Groundwater Sampler is a discrete interval ground water sampling device that can be pushed to pre-selected sampling depths in saturated, unconsolidated materials. Once the target depth has been reached, the screen is opened and groundwater can be sampled as a temporary monitoring well, which yields a representative, uncompromised sample from that depth. Using knock-out plugs, this method also allows for grouting of the push hole during sample tool retrieval.

The Screen Point® 15 sampler consist of four parts (drive point, screen, sampler sheath and drive head), with an assembled length of 52 inches (1321 mm) and a maximum OD of 1.5 inches (38 mm). When opened, it has an exposed screen length of 41 inches (1041 mm). It is typically pushed using 1.25-inch probe rod. The Screen Point® 16 consists of the same parts and works in the same fashion, the only differences being larger diameter and its use with 1.5” rods.

4.1.1 Assembly of Screen Point® 15/16 Groundwater Sampler

1. Install O-ring on expendable point and firmly seat in the angled end of the sampler sheath.

2. Place a grout plug in the lower end of the screen section. Grout plug material should be chosen with consideration for site specific Data Quality Objectives (DQOs).

3. When using stainless steel screen, place another O-ring* in the groove on the upper end of the screen and slide it into the sampler sheath.

4. Place an O-ring* on the bottom of the drive head and thread into the top of the sampler sheath.

5. The Screen Point® 15/16 Groundwater Sampler is now assembled and ready to push for sample collection.

   * It should be noted that O-ring use in steps 3 and 4 are optional.

4.1.2 Installation of Screen Point® 15/16 Groundwater Sampler

1. Attach drive cap to top of sampler and slowly drive it into the ground. Raise the hammer assembly, remove the drive cap and place an O-ring* in the top groove of the drive head. Add a probe rod and continue to push the rod string.

2. Continue to add probe rods until the desired sampling depth is reached.

3. When the desired sampling depth is reached, re-position the probe derrick and position either the casing puller assembly or the rod grip puller over the top of the top probe rod.

4. Thread a screen push adapter on an extension rod and attach sufficient additional extension rods to reach the top of the Screen Point® 15/16 sampler. Add an extension handle to the top of the string of extension rods and run this into the probe rod, resting the screen push adapter on top of the sampler.

5. To expose the screened portion of the sampler, exert downward pressure on the sampler, using the extension rod and push adapter, while pulling the probe rod upward. To expose the entire open portion of the screen, pull the probe rod upward approximately 41 inches.

6. At this point, the Screen Point® 15/16 Groundwater Sampler has been installed as a temporary well and may be sampled using appropriate ground water sampling methodology. If waters levels are less than approximately 25 feet, EIB personnel typically use a peristaltic pump, utilizing low-flow methods, to collect ground water samples from these installations. If water levels are greater than 25 feet, a manual bladder pump, a micro bailer, or other method may have to be utilized to collect the sample (SESD Operating Procedure for Groundwater Sampling, SESDPROC-301-R0) provides detailed descriptions of these techniques and methods).

4.1.3 Special Considerations for Screen Point® 15/16 Installations

<u>Decommissioning (Abandonment)</u>

In many applications, it may be appropriate to grout the abandoned probe hole where a Screen Point® 15/16 sampler was installed. This probe hole decommissioning can be accomplished through two methods which are determined by location and contamination risk. In certain non-critical areas, boreholes may be decommissioned by filling the saturated zone with bentonite pellets and grouting the vadose zone with neat cement poured from the surface or Bentonite pellets properly hydrated in place. Probe holes in areas where poor borehole sealing could present a risk of contaminant migration should be decommissioned by pressure grouting through the probe rod during sampler retrieval. To accomplish this, the grout plug is knocked out of the bottom of the screen using a grout plug push adapter and a grout nozzle is fed through the probe rod, extending just below the bottom of the screen. As the probe rod and sampler are pulled, grout is injected in the open hole below the screen at a rate that just fills the open hole created by the pull. Alternatively, the screen can generally be pulled and the hole re-probed with a tool string to be used for through-the-rod grouting.

Screen Material Selection

Screen selection is also a consideration in sampling with the Screen Point® 15/16 sampler. The screens are available in two materials, stainless steel and PVC. Because of stainless steel's durability, ability to be cleaned and re-used, and overall inertness and compatibility with most contaminants, it is the material typically used during EIB investigations.